Enhancing U.S. Technology Development Through Lifelong Education of Engineers and Technologists as Creative Professionals

University of South Carolina / Purdue University / University of Alberta
Loyola Marymount University

Abstract

There is growing recognition worldwide that traditional graduate engineering education neither fits the engineering innovation process necessary for competitiveness in the global economy nor reflects the way that graduate engineers and technologists learn and develop as professionals, innovators, entrepreneurs and leaders in industry. In today’s global economy, engineering innovation is recognized as a continuous, systematic needs-driven process, which is highly dependent upon the provision for lifelong learning, growth, and development of the nation’s graduate engineers and technologists in industry beyond their entry-level undergraduate baccalaureate preparation. Because of profound changes in engineering practice for real-world innovation, a transformation is underway in the U.S. Science and Engineering (S&E) innovation system. A concurrent, nonlinear model of needs-driven systematic engineering innovation, which is supported by directed scientific research, is replacing the sequential, linear research-driven model of engineering innovation. Graduate education must be responsive to this change and must build a new type model of in-service graduate professional education which reflects the substantial changes and characteristics of the engineering innovation process itself, and the stages of lifelong growth, professional dimensions, and leadership responsibilities associated with the modern practice of creative engineering in a knowledge-based, innovation-driven economy. Whereas traditional research-based graduate engineering education and teaching have resulted during the last three decades as a byproduct of the linear research-driven model of innovation, a new model of graduate professional education has been developed which focuses on lifelong professional education for emerging and experienced engineering leaders in industry as creative problem-solvers, technical program makers, technology policy makers, and leaders in the modern context of engineering practice for creative technology development and innovation.

1. Introduction

More than ever, science, engineering, and technology are key to economic performance and social well being of industrialized nations. The ability to continuously create, develop, and innovate new and improved technology is rapidly becoming the major source of competitive advantage, worldwide, for sustained economic growth. The United States faces stiff competition in the global arena as other nations are also recognizing that growth performance in the new economy is dependent upon technological innovation. There is growing awareness, however, that fundamental changes have occurred in the 1990s with regard to the technological innovation process itself, and a new model of engineering innovation has emerged.
Based on the findings by the Organization for Economic Co-operation and Development (OECD) and by the nation’s distinguished Council on Competitiveness, it is now clear that fundamental changes have occurred in the model of the technological innovation process itself, which are transforming the respective roles of U.S. industry, research universities, and government in stimulating innovation for economic growth. But substantial changes need to be made in reshaping graduate professional education for the nation’s engineers and technologists in industry to reflect these changes in order to improve U.S. competitiveness.

As the Organization for Economic Co-operation and Development (OECD), of which the United States is a member nation, points out: 1 “With the emergence of a knowledge-based society, innovation has become an increasingly important factor in the competitiveness of firms, the prosperity of nations and dynamic world growth. Promoting innovation is now a high priority in most OECD countries. However, the pursuit of this objective is often hampered by an inadequate understanding of the extent to which the mechanisms of innovation are being transformed by globalization … the innovation process itself is undergoing profound changes.”

2. The Changing Climate for Technological Innovation

2.1 OECD Findings and Conditions for Technological Innovation

As the OECD findings point out, the relationship between conditions for success, technological progress, innovation and growth appears to have changed in the 1990s. The OECD findings reflect that there are several characteristics that combine to change the conditions for successful innovation: 1

1) **Innovation is a creative and interactive process that is driven by market-articulated demands and other social needs.** “The relationship between science, technology and economic performance appears to have changed in the 1990s. The process of innovation is undergoing substantial change. The main driving forces are increasing market pressures (stemming from globalization, deregulation, changing patterns of demand and new societal needs) that lead to a closer integration of technology in commercial strategies, as well as scientific and technological developments.”

2) **Innovative companies are the central actors in innovation but they do not act alone.** “Firms are the main vectors of technological innovation … The innovativeness of firms depends on the incentives they face, their own competencies, and the efficiency of their external linkages with other firms and institutions (networks and clusters). Their capacity to innovate is partly determined by their own capabilities, partly by their capacity to adopt and apply knowledge produced elsewhere. Innovation uses various forms of knowledge when responding to market-articulated demands and other social needs. Technical knowledge can be “codified” (in the form of publications, patents, blue-prints, etc.) or “tacit” (embedded in the “know-how” and dexterity of individuals, in organizational routines and the like). It can be “scientific” (stemming from either basic or applied research) or it can be “production and engineering” knowledge (e.g. derived from hands-on experience with production processes or from testing and experimenting).”
3) **Innovation depends on framework conditions.** “Firms innovate when they are motivated to do so and can afford the required investment. The business environment influence them in many ways. If markets are not competitive or contestable enough, firms can derive monopoly rents from safer investment and will have fewer reasons to take the risk of innovating. All factors that discourage investment in general (e.g. high interest rates, inflation, volatility of exchange rates, etc.) will have a negative effect on innovation and technology diffusion. Compared to alternative business strategies, other factors reduce the attractiveness and feasibility of innovation: a financial sector unable to assess innovative projects, weak protection of intellectual property which reduces the rewards for creativity, regulations which increase risks and costs of commercialization of innovative products or processes, etc.”

4) **Innovation increasingly relies on effective interaction between the engineering base in industry and directed scientific research at universities.** “Innovation results from complex interactions between research, design, production and marketing that take place in a web of interactive learning within and among firms and other knowledge organizations. The innovative process is increasingly characterized by feedback between engineering and scientific research in the different stages of technology development and commercialization. More competitive markets and the accelerating pace of scientific and technological change force firms to innovate more rapidly.

In this changing environment, innovation has become more market-driven, more rapid and intense. The interface in a National Innovation System and the enterprise sector is an important one. However, industries and countries with different industrial specialization patterns differ greatly in their reliance on the science base, and few have strong direct links with basic research. Except in such industries, scientific knowledge stemming from basic research is rarely a direct input into technological innovation. However, it is an essential indirect input into the process of technological innovation in many industries....A greater part of the scientific research agenda is driven by problems identified during the course of technological development in industry.”

5) **Innovation depends on building innovation capacities and innovation cultures in industry.** “There is increasing evidence that the innovation capacities of most firms, especially SMEs (Small and Medium Enterprises), are limited … Not only do many firms not innovate, innovative firms also vary in their level of competence. A key policy challenge is to help non-innovative firms acquire basic capabilities and more competent firms to increase their level of innovativeness. In broad terms, one can distinguish four levels of innovativeness, irrespective of firm size and activity:

- Level 0 – *The static firm* innovates seldom or not at all, but may have a stable market position under existing conditions.
- Level 1 – *The innovating firm* has the capability to manage a continuous innovation process in a stable competitive and technological environment.
- Level 2 – *The learning firm* has, in addition, the capability to adapt to a changing environment.
- Level 3 – *The self-regenerating firm* is able to use its core technological capabilities to reposition itself on different markets and/or create new ones.
The new technology-based firms (NTBFs), which play an increasingly important role in innovation systems, illustrate well the existence of these “competence thresholds” and the implications for government policy. Whereas some NTBFs are condemned to a short life span because of a defective business plan, many others will not achieve a sustained growth trajectory because of the absence of a corporate governance structure able to adjust to changing conditions. A successful NTBF requires superior governance and management capabilities, including comprehensive understanding of product technology, manufacturing technology, market research, financial planning, accounting, legal aspects, contracts and networking, as well as a supportive environment of relevant business services.

6) **Innovation depends on promoting networking and clustering.** “When identifying barriers to greater innovativeness, it is necessary to take into account that firms differ from large ones in the skills and professional training of their managers and in the profile of their innovation capacities. Large and smaller innovative firms have important common needs: commitment from the top; an integrated view of innovation strategy and business strategy; a clear idea of the firm’s distinctive competencies; an openness to constructive ideas and contributions from all staff; a structured way of watching and responding to changes and opportunities in the business environment. However, smaller firms tend to have more limited financial and human resources, less ready access to information, and shorter time horizons. In addition, they are generally more risk-averse and reluctant to engage outside help, except for very specific short-term needs.

Firms have become more specialized and increasingly focus on their core competencies. For complementary knowledge and know-how, they increasingly rely on interaction with a variety of actors (e.g. equipment and component suppliers, users, competitors and non-market research institutions such as universities or government laboratories). Inter-firm collaboration is by far the most important channel of knowledge sharing and exchange. Creating appropriate conditions for such collaboration thus poses a key policy challenge… Networking has in fact become an effective innovation technique in its own right. Empirical studies have confirmed that collaborating firms are more innovative than non-collaborating ones. Relationships are selective, durable and trust-based. Firms tend to establish selective relationships, which are relatively stable in the medium- to long-term. Network building is a slow process, which relies on affinity and builds loyalty.”

7) **Innovation depends on the way in which the different components of the innovation system (industry, universities and government) interact with one another at the local, national and international levels.** “Innovative competitiveness requires that public authorities must change their approach to the promotion of innovation. The innovation process itself is undergoing profound changes. To realize the full potential of new technologies for growth and jobs, OECD governments must respond effectively to such changes. They face the common task of strengthening innovation systems in order to take greater advantage of globalization and the move to a knowledge-based economy. In general, there is a need for new approaches to stimulating innovation that provide greater scope and incentives to private initiative and are less dependent on direct government financial support.”
Governments should help the science system adjust to the emerging entrepreneurial model of knowledge generation and use, while ensuring the continued pursuit of curiosity-driven research.

On the basis of a review of more recent thinking on innovation and best practices, the Focus Group on Innovative Firm Networks identified six main groups of capacities, which underlie innovation in all types of firms and sectors: managing the competence base, vision and strategy, creativity and idea management, intelligence, organization and process, culture and climate.

2.2 The U.S. Council on Competitiveness Findings and Conditions for Technological Innovation

In a similar vein, the Council on Competitiveness, whose members include corporate chief executives and university presidents, issued a call for transformation in the U.S. Science and Engineering (S&E) innovation system, a decade before. In the major report, “Picking Up the Pace: The Commercial Challenge to American Innovation,” the Council issued its findings on innovation, which reflect that the model for successful technological innovation has undergone substantial transformation worldwide, and that the United States must adjust its national innovation system and its infrastructure in higher education accordingly. As the Council’s report reflects:

1) The model for technological innovation has changed worldwide in the civilian economy with little awareness in the U.S. “By aggressively developing and commercializing new technologies, foreign companies have achieved considerable economic success, some times taking over entire industries … It was not until several American industries had been dominated by foreign competitors and the United States began to lose its substantial lead in technology that the country began to recognized the extent of the foreign commercial challenge. Part of that challenge relates to the innovation process itself.

Throughout the 1970’s, as trade deficits in U.S. “smokestack” industries mounted, we comforted ourselves with the notion that foreign commercial successes did not really matter since the economic future lay with “sunrise” high-technology industries. In 1986, however, we suffered our first high-technology trade deficit; and in 1987, despite the decline of the dollar, we registered only a modest high-tech trade surplus.

Then, we told ourselves that while other nations might be able to take advantage of lower wages and an overvalued dollar to make and sell products more cheaply, those countries were incapable of innovation themselves. Today, about half of all the patents awarded in the United States go to foreign inventors, and an increasing percentage of these patents are the important ones.”

2) The U.S. must regain its innovative capacity to sustain competitiveness. “We cannot afford any further erosion in our once-commanding technological lead … Because technology is a driving force behind productivity improvements, export strength and a high standard of living, the stakes are enormous … The Council on Competitiveness recognizes that the private sector has the primary responsibility for commercializing technology. It alone can
develop, produce and market new products and processes... however, we focus on the
government’s role for two reasons. First, public policies undeniably create the climate in
which American scientists, engineers, manufacturers and managers work. Second, and more
important, the federal government is in a position to create public awareness of technology’s
central role in revitalizing American competitiveness and to promote the cooperation
necessary to turn that awareness into national action.

The primary challenge for policy-makers is to develop a new public policy framework for
technology that is appropriate for today’s global competitive environment. While other
governments have used science and technology policies to promote industrial growth,
commercial spin-offs from U.S. government programs, if they occurred at all, have been
incidental. Because the ability of American firms to identify, develop and commercialize
technology is critical to our ability to compete in world markets, it is essential for the
government to promote these private sector efforts systematically.

3) The U.S. framework for action must be guided by a new understanding of the needs-
driven technological innovation process. “In developing a framework for action, both the
public and private sectors should be guided by a new understanding of the innovation
process. Part of the reason for the erosion of American’s technological lead is that we have
tended to view progress in science and technology as a relay race, a step-by-step process
whereby the “basic research runner” handed the baton to the “applied research runner,” who
handed off to the development and marketing specialists, and so on. Many of our efforts in
the past few decades have concentrated on ensuring that the first runner — the basic
researcher — exploded out of the blocks with a breakthrough invention that provided enough
of a cushion for the rest of the team to coast to victory.”

4) The innovation process has undergone substantial change and a new model of
 technological innovation has evolved. “The innovation game, however, has changed. Instead
of a relay race, research and development require a total team effort — where individual
heroics are subordinated to a coordinated team approach, where systematic long-term
progress is more important than a fast start out of the blocks. In many ways, foreign
competitors are the driving force behind this new approach to innovation; and in many
instances they have capitalized on it ahead of U.S. companies and the federal government.
Because the approach to technology has changed, so must public policy.

Four decades ago America restructured its technology and science policies in response to the
challenge of the post-war setting and entered an era of unparalleled scientific achievement.
Today, spurred by the commercial gains of foreign competitors, America must respond
again. Increased government attention to, and support for, the commercialization of
technology is a vital part of that response ... Countries without a large scientific base have
made up for shortcomings in research by concentrating industrial resources on the rapid
commercial application of new ideas ... The United States, long used to preeminence in basic
research, has been slow to recognize the changing nature of technological competition. As
the nation wakes up to this new reality, it must reassess the roles played by all sectors —
industry, academia, labor and government.”
5) The nation must build its infrastructure in the Science and Engineering (S&E) innovation system on the correct model of systematic technological innovation to enhance industry's competitiveness. “The effective development and deployment of technology is critical to America’s ability to compete in world markets. Technology has made a vital contribution to America’s economic growth and high standard of living. It has improved manufacturing efficiency, created entire industries and served as an important source of U.S. export strength. Leading economists believe that technological change is the single most significant factor behind U.S. productivity growth.

The United States is not alone in its increasing focus on science and technology … In today’s international economy, virtually all aspects of the commercialization process have become globalized. The reality of a globalized scientific and technical community has profound implications for corporate strategy and the commercialization process … A new (innovation) model has emerged, however, and America’s current difficulties in the global technology race have occurred, in part, because neither U.S. industry nor the federal government has responded sufficiently to that new reality … Technology innovation is closely linked to systematic, incremental improvements that are driven by market needs.

Simplistically defined, the research-driven model views innovation as a linear process — starting with a major scientific breakthrough, progressing through design, development and production, and ending with marketplace distribution. Consequently, this model emphasizes the importance of basic research … As a growing number of observers recognize, however, the research-based model offers, at best, a partial explanation of the innovation process. It is far more complex than suggested by this linear concept. Consequently, the research-based model must be supplemented by another view that focuses more on market-driven applications of technology. This approach involves systematic, incremental improvements in products and processes that arise in response to market needs. These improvements — which, in the aggregate, can be as significant as a radical discovery, if not more so — depend on day-to-day adaptation as firms react to ever changing market signals.”

6) A new model of needs-driven, market-focused and continuous systematic technological innovation has evolved based upon the concurrent, interdependent, and interactive strengths of systematic creative engineering in industry and directed scientific research. “The new model suggests that innovation is better described as an interactive or reiterative interdependent process in which design, manufacturing and product development all drive research and, at the same time, are highly dependent on research. This approach involves systematic, incremental improvements in products and processes as firms react to ever-changing market signals. Many of America’s problems stem from not rapidly moving new innovations into the marketplace … When the United States so thoroughly dominated the world economy, the speedy translation of new ideas into practical products and processes was not a crucial factor in commercial success. International competition has changed that situation. For technology-based industry, a failure to focus on the rapid application of new ideas can be devastating … Commercialization involves applying fresh ideas to market opportunities to create new and better products. It is the primary job of the private sector. Innovations are brought to market through a firm’s internal operations, which combine research, concept identification, development and implementation.”
7) **Whereas the federal government has based its civilian policies for the development of technology upon a 1945 linear research-driven model and science policy, it has largely ignored the educational development of the nation’s creative engineering capacity in industry by treating technology as “applied science” and as a sequential follow-on to scientific research.** “The federal government has not focused on the commercial application of technology as a public policy issue. As a result, current government policies and procedures tend to inhibit rather than accelerate rapid commercialization.

In many ways, America’s hands are tied by policies geared to another era that do not address today’s competitive realities. Since the end of World War II, U.S. government sciences and technology programs have been dominated by two overriding concerns: basic research and support for specific national missions, such as national security and health. Largely as a result of this concentrated federal effort, American science has enjoyed an era of unprecedented excellence … In many ways, the federal government has failed to adapt its policies to the new, market-driven model of innovation. Considerable evidence suggests that America is failing to commercialize the kinds and quality of technology that the market demands.”

8) **U.S. industry must rebuild its in-house innovative engineering capacity and its leadership capacity to stimulate technological innovation to sustain economic competitiveness for the long term.** “All too often American management is under pressure to improve the bottom line in the next quarter, without regard to how their actions will affect business in the future. This problem is not simply a result of myopic management; it is systemic … Unfortunately, preoccupation with short-term goals can be devastating for technology-based industry. R&D, manufacturing excellence and the creation of a talented labor force are inherently long-term propositions. Science and technology thrive in organizations where there is a critical mass of highly skilled talent and a sense of mission. Systematic investments in research, plant and equipment, and in training and retraining are essential.

Problems in manufacturing and in setting long-term goals attest to the fact that American managers often lack the benchmarks to understand and evaluate their companies’ performance in the R&D cycle. As a result, they have difficulty accurately identifying specific problem areas. Better information about each of the steps in the R&D cycle is required, from research through design, manufacturing and marketing.

More important, management needs to establish a new set of benchmarks that will allow it to survey the private sector’s R&D cycle and address problems … Succeeding in the global scientific and technological race depends on an ability to integrate a number of capabilities over a sustained period of time. Focused research, excellence in manufacturing, commitment to quality, incentives for worker motivation and upgraded employee skills are all part of the process. There is no doubt that the commercial challenge to American innovation is the result of problems within American industry. But industry’s performance is vitally affected by federal macroeconomic policy, regulatory polices and by government science and technology policies.”
9) The federal government must reshape its policies to advance both scientific research and the creative “practice of engineering” as the foundations for U.S. technological progress. “In staking out a forceful role in the advancement of scientific knowledge, the government has tended to ignore technology. The American people and public officials too readily assumed that preeminence in science automatically confers technological and commercial success as well. It does not. America assumed that government support for science would be adequate to provide for technology. It is not. In all too many sectors, America took technology for granted. Today, the nation is paying the prices for that complacency.

Existing federal science and technology programs do not adequately recognize the new market-driven model of innovation … America’s ability to commercialize technology is linked closely to its supply of skilled technical workers. Clear signs, however, show that the nation faces significant human resource problems. The challenge is two-fold. First, the nation’s most experienced scientists and engineers, who were recruited shortly after the launching of Sputnik, will be retiring in the 1990s. Second, by the year 2000 the number of jobs requiring college degrees will increase dramatically. Unfortunately, the education system is failing to produce the American scientists and engineers needed to meet future demand. Leadership in science and technology cannot be maintained unless the education pipeline—from elementary school through graduate school—is repaired so it yields a larger and more diverse group of world-class scientists and engineers.”

10) The Council on Competitiveness reiterated its findings for transformation in the nation’s innovation system in its follow-on report, “Endless Frontier, Limited Resources: U.S. R&D Policy for Competitiveness (1996).” The Council’s 1996 Report recognizes that a paradigm shift is necessary for the United States to reinforce its Science and Engineering (S&E) innovation system and higher educational infrastructure for competitiveness in order to respond to new knowledge about the transformation of the innovation process itself. The paradigm shift requires a shift in focus from a singular emphasis on the nation’s academic scientific research system and linear research model to a broader conception of what is in the national interest in all aspects of the U.S. Science and Engineering (S&E) innovation system, which in the long-term will also strengthen the nation’s research universities, their higher education missions, and their outreach with industry.

The report specifically reflected its concerns with the universities as follows: “Looking ahead, U.S. research institutions must decide how to cope with competing pressures to conduct the lion’s share of the nation’s research in basic science, to increase their involvement in shorter-term research, and to provide the pool of human resources needed to meet national needs … These decisions will require universities to define their own priorities more clearly and to reassess their links both with industry and the federal system … American universities have an indispensable role to play in developing the nation’s human capital in science and technology. No agenda for R&D will succeed for long unless the United States produces a steady stream of students well-educated in science and engineering … The most vital mission of U.S. universities is education: it is a mission that no other institution can perform. All other activities at universities should support or be subordinate to the education mission.”
3. The Integrative Roles of Science and Engineering (S&E) in the U.S. Innovation System for Technology Competitiveness

3.1 Outgrowing a Simplistic Model of Innovation

The U.S. science policy, and its supporting graduate education system, was initially devised in 1945 as a result of the Vannevar Bush Report: Science—The Endless Frontier. This policy was based upon a linear research-driven model of technology innovation, wherein the creation of new fundamental scientific knowledge and the development of new scientific talent for academic research would occur simultaneously through public funding of basic research and research-based graduate education at the nation’s top research universities, and the new scientific knowledge would be transferred for further exploitation, engineering development, and commercialization in industry.

After four decades, however, there is growing recognition worldwide that the simplistic linear research-driven model doesn’t fit the needs-driven systematic engineering innovation process, nor does the linear research-driven model of educating engineers at the graduate level — to be either basic scientific researchers or strategic researchers — fit what most creative engineering leaders do in industry. As Eric Bloch, former director of the National Science Foundation and Distinguished Fellow on the Council on Competitiveness, pointed out in his distinguished address at the University of South Carolina:

“We can’t continue to say that trade is a growing share of the U.S. economy, imports are growing at a faster rate than exports. There is amazingly little concern about this issue. We have looked for excuses … the real reason is that we are not producing enough high value products, which points to a failure in our innovation system … In 1945 Vannevar Bush, then Director of the Office of Technology, the equivalent of today’s Science Advisor to the President, submitted his blueprint for the nation’s research enterprise in his report “Science, the Endless Frontier.” Underlying Bush’s recommendations was a simple model, what today is called the Linear Model of R&D. His viewpoint was that there is an orderly and sequential, unidirectional progression from basic research to applied, to development, manufacturing and marketing.

With this model as a premise, Bush advocated for government to fund basic or blue-sky research and leave all other R&D funding to industry … Many of today’s government policies and legislation spring from this simplistic understanding of the process of research. Many of industry’s organizational approaches are based on it. Today, we know the innovation process is more complex. We recognize that basic understanding does not always precede applications and that the innovation model is not sequential, but highly concurrent and parallel … The flow of knowledge is not unidirectional.”

3.2 Moving from the Linear Research-Driven Model to an Integrative Model of Needs-Driven Systematic Engineering Innovation and Directed Scientific Research

Although the academic community has been slow to recognize and to accept the calls for needed change, a silent transformation from the sequential linear research model of innovation to the new interdependent (S&E) model of innovation, which integrates directed scientific research
concurrently with needs-driven systematic engineering innovation for technological progress, has
been underway in America for the last ten years to enhance the U.S. Science and Engineering
(S&E) innovation system for sustained technological competitiveness. The academic
transformation, however, has awaited the legitimization of the new model of purposeful
systematic technological innovation, which is now gathering increased momentum in universities
across the country with industry’s support.

The need for accelerated educational transformation, which supports the new model of needs-
driven systematic engineering innovation, grows in importance as technological competitiveness
by other nations increases in the global economy. In essence, although the 1945 Vannevar Bush
Report gave the nation a superior model for scientific progress, developed a compact between
the government and universities for basic academic research, and developed a preeminent
system of graduate education for academic scientific research, the Bush Report placed singular
emphasis on a model that is no longer sufficient to sustain the nation’s future engineering
progress for technological advancement and economic growth.

As Mary Good, former Undersecretary for Technology at the U.S. Department of Commerce and
president of the American Association for the Advancement of Science, pointed out in 1998:
“Absolutely everyone agrees that the linear model is wrong. Policy based on it is destined to fail
because it’s not reality.” As Good further noted: “The science community has argued for
science policy, when all of us should have been arguing for science and technology policy … our
future will depend on the ability of the nation to be innovative.”

3.3 A Paradigm Shift in the U.S. Science and Engineering (S&E) Innovation System

There is increasing national awareness, based on a new understanding of the mechanisms of
engineering innovation, that a paradigm shift in the U.S. Science and Engineering (S&E)
innovation system has occurred. A nonsequential but integrative model of proactive needs-driven
systems-engineering practice, which is supported concurrently by directed scientific research,
has evolved for creative technology development.

Today, the lion’s share of U.S. engineering innovation results as the deliberate outcome of
purposeful “systematic engineering practice” for needs-driven creative technology development,
which requires a new understanding that scientific research and “systematic engineering
practice” are not sequential processes but are concurrent and parallel activities which are vital
critical components in the U.S. innovation system. In this deliberate process, systematic
engineering innovation and academic scientific research are not competitors in the nation’s
innovation system — but they are interdependent and vital components with different roles and
responsibilities. This paradigm shift has been underway in American industry and in U.S.
motion-oriented government agencies for several years. Transformation in the U.S. higher
education system, however, has awaited the legitimization of the new model of needs-driven
systematic engineering practice for creative technology development, which is now gathering
increased momentum at research universities and in engineering schools across the country with
industry’s support.
The need to reshape U.S. graduate education by developing a new complementary type of professional-oriented graduate education for engineers, which better supports the mechanisms of needs-driven systematic engineering practice for innovation, grows in importance as America increasingly faces stiff competition in the global economy. As Ferguson pointed out in 1993, although the 1945 report, Science—The Endless Frontier, gave the nation a superior model for scientific progress and a system of graduate education for academic scientific research, the 1945 report virtually ignored creative “engineering practice.” It placed singular emphasis on a simplistic model of research-driven innovation and scientific graduate education that is neither sufficient nor adequate to fully sustain the nation’s future engineering progress for economic growth or to professionally educate the nation’s engineers for leadership of innovative engineering practice for technological innovation. As Bloch and others have pointed out: “the innovation model is not sequential, but highly concurrent and parallel ... and the flow of knowledge is not unidirectional.”

3.4 Breaking Through Tradition

Nevertheless, in the past, and still today, there has been public confusion between the vital roles of needs-driven systematic engineering practice in industry and that of academic scientific research at the nation’s research universities largely because of the pervasiveness of the sequential research-driven model of engineering innovation. The singular emphasis on graduate academic scientific research as the forerunner of engineering innovation has caused an underemphasis in the nation’s human resource development of innovative engineering capacity in U.S. industry, which has hindered U.S. technological competitiveness over the long run. The underdevelopment in America’s innovative engineering capacity is not because of the development since the 1970’s of excellent research-based graduate education for academic scientific research but rather because of the underdevelopment since the 1970’s of a parallel, complementary type program of excellent professional-oriented graduate education for “engineering practice” to further enhance capacity for leadership of engineering innovation in U.S. industry.

What has occurred in the U.S. higher education system during the past three decades (with notable exceptions) has been primary emphasis on research-based graduate engineering education with the underlying belief that scientific research is the primary key driver for engineering innovation. In essence American graduate engineering education, which has been funded largely by federal research dollars, has patterned a simplistic sequential model of engineering innovation for civilian economic growth, whereby graduate engineering education today is largely a byproduct of research not wholly of the university’s own making. As Ferguson points out:13

“From Bacon’s time to the present — more than 350 years — promoters of the mathematical sciences have convinced their patrons that science is the way to the truth and that it is also the chief source of the progressive inventions that have changed the material world. The myth that the knowledge incorporated in any invention must originate in science is now accepted in Western culture as an article of faith, and the science policies of nations rest on that faith. ... The myth was restated in the report, Science — The Endless Frontier.”
3.5 Redefining the Relationship Between Academic Research and “Engineering Practice”

It is now understood that the systematic method and purpose of academic scientific research is different from that of the systematic method and purpose of needs-driven engineering innovation to meet real-world needs. As Drucker points out: “… For, contrary to almost universal belief, new knowledge — and especially new scientific knowledge — is not the most reliable or most predictable source of successful innovations. For all the visibility, glamour, and importance of science-base innovation, it is actually the least reliable and least predictable one.”

As Drucker notes the electrical engineer Charles Steinmetz was one of the first “heretics” to transform, and breakthrough conventional wisdom regarding the relationship of science and technology. Steinmetz, as Drucker notes, had two clear objectives from the start: “To organize for purposeful technological invention and to build continuous self-renewal through innovation into the corporation.” Toward this aim, Steinmetz organized goal-oriented creative engineering development projects around meaningful needs: “Beginning with a clear definition of the expected end result and identification for the steps in the process and of their sequence.” Drucker further notes, that Steinmetz organized multidisciplinary teams of people with diverse skills around the development projects, which violated the sacred 19th century principle of maximum scientific specialization.

To go one step further in heresy, Drucker notes that Steinmetz radically redefined the relationship between science and technology in his engineering development projects “to deliberately design and develop new product lines.” In defining the goals of the development project, Steinmetz also determined what “phenomenon” needed to be known or better understood to assist in product development. He then directed scientific research teams in these specific areas to gain a better understanding and to obtain new scientific knowledge of the “phenomenon” involved. In other words, in the purposeful, systematic engineering practice of needs-driven creative technology development, there are frequently times when the technology development project drives directed scientific research — and, the systems-engineering leader must know when and how to organize for this.

As Drucker points out: “In Steinmetz’s lab, science — including the purest of pure research — is technology-driven, that is a means to a technological end.” As Drucker notes, Steinmetz’s technology management concept and organizational approach: “is indeed anathema to many academic scientists.” Whether or not it is an anathema to many researchers in academia, the purposeful, systematic engineering practice of needs-driven creative technology development is not anathema to most creative engineers in world-class technology-based organizations. But academic scientific research and “engineering practice” for creative technology development are different in mission, purpose, objectives, and scope.

However, a misunderstanding of the engineering method for the generation, development, and innovation of new and improved technology exists. As Drucker notes: “Technology, traditional wisdom held and still widely holds, is applied science.” The sequential linear research culture and belief system — that scientific research drives technology innovation — exists, is conveyed to engineering students by research-oriented faculty, and is pervasive in higher education.
throughout the nation. And America’s science policy and national goals for civilian-oriented technology have been built on this belief system during the last three decades.

3.6 Differentiating Characteristics: Between Academic Scientific Research and Needs-Driven “Engineering Practice” for Systematic Technology Development and Innovation

As Ferguson has pointed out, the 1945 Bush report placed singular emphasis on the linear research-driven model of technology innovation and virtually ignored use of the purposeful needs-driven engineering method, which was used by innovative engineers in the nation’s technology-based industry and mission-oriented government service. Whereas, in the past, the linear research-driven model essentially defined technology development as “applied science” and defined engineering as primarily a secondary follow-on, conversion process that converted new scientific knowledge, generated at the research universities into technology, new definitions of “systematic engineering practice” for creative technology development have emerged through “innovation best practice” in U.S. industry and in mission-oriented U.S. government service.

Rather than defining academic scientific research as the forerunner for engineering innovation in the U.S. Science and Engineering (S&E) innovation system, engineering innovation in the United States is now being defined differently and proactively by a different driver — wherein academic scientific research is now seen to be a contributor in the engineering innovation sequence for creative technology development and innovation rather than the initiator. As Martino, formerly of the U.S. Air Force Office of Scientific Research, pointed out: 16

“Research and development are two entirely different categories of activity … The term research is defined here as an attempt to acquire new knowledge about some phenomenon in the universe, or about some phenomenon in an abstract model of a portion of the universe, which is not necessarily made with an application in mind. The definition makes no distinction between basic and applied research, since the difference between the two terms is usually in the motivation of the researcher, and this is not an objectively measurable quantity. Although an application may well be in the researcher’s thoughts, no inference is made here about what is going on in his mind while he is doing his research.

There is, however, a meaningful distinction between research and development: development is an attempt to construct, assemble, or prepare for the first time, a device, material, technique, or procedure, meeting a prescribed set of specifications or desired characteristics and intended to solve a specific problem. This definition includes not only mechanical devices and hardware, but also such things as computer programs, chemicals and other materials. The essence of this definition is that development is intended to meet some set of specifications in order to solve a specific problem.

The interaction between research and development as shown (below) depicts a common model of the way research progresses into products.

Research⇒Exploratory Development⇒Advanced Development⇒Systems Engineering
This is usually phrased in such terms as getting an idea out of the laboratory and into production. The kindest thing one can say for this model is that it is erroneous. Research and development are two entirely different categories of activity, and there is no neat linear progression from one into the other, as this model would imply.”

3.7 The Systems-Engineering Approach to Needs-Driven R&D: Lessons Learned Using Directed Engineering Development and Directed Scientific Research to Meet Real Needs

Today, U.S. competitiveness requires that technology development be undertaken primarily from a systems-engineering approach that is customer focused, needs-driven, purposeful, systematic, and continuous. However, as Gregory and Turner point out: 17 “There is a common belief that new systems come to life as the result of the availability of new knowledge. This assumed mechanism, sometimes called knowledge-push, lies at the back of much academic thinking.” Another common belief is that technology is something live that grows on itself — “it keeps on growing and growing, as natural occurring progress.” Contrary to popular belief, as Gregory and Turner point out, it doesn’t. Neither of these lingering beliefs recognizes the impact of using the modern systems-engineering approach to “R&D” in today’s innovation-driven economy nor the vital impact that the integrated combination of needs-driven systematic engineering practice in industry and directed scientific research at the nation’s research universities plays in the success of the U.S. Science and Engineering (S&E) innovation system for sustained economic growth and technological competitiveness.

As Sanders and Brown point out: 18

“The great discovery of our age is that technological innovation need not be haphazard. Industry and government have developed a new concept of planned and systematized innovation, founded on vastly expanded scientific and engineering efforts.”

Today, the managed combination of integrating needs-driven directed systematic engineering practice for innovation in industry with directed phenomenon-oriented scientific research at the nations research universities can become a formidable strength of the U.S. Science and Engineering (S&E) innovation system for the development of small, moderate, and large scale complex technological systems for U.S. competitive advantage. Both needs-driven systems-engineering development in industry and directed scientific research at the universities are essential to America’s competitiveness for economic growth and sustained technological progress. But engineering and research are two different intellectual pursuits, with different missions, methodologies, and objectives. Each method is systematic, but each allows room and intellectual thought for experiences learned and original creativity to occur. As McCrory pointed out at Battelle Memorial Institute: 19

“The engineering (design) method parallels the scientific method. Each is a closed loop, with experiences gained during the execution and completion of the process providing the basis for subsequent applications of the method. Both the scientific method and the engineering method have stages, defined plateaus, which can be used to identify when a recognizable degree of attainment has been reached.
To progress from one stage to the next, each method requires that certain intellectual powers be brought to bear. The engineering method is compounded by multiple interconnecting steps and auxiliary stages. But these are ancillary to the basic methodology and can vary, depending upon individual situations.

The starting point of the engineering method is more comprehensive than that of the scientific method. Unlike fundamental scientific research, engineering is motivated by need rather than by curiosity. Therefore, in addition to requiring knowledge of the state of the technical art, the engineering method requires recognition of a need, which warrants an investment of effort and funds … Recognition of need can be considered the marketing input to the engineering method … this input involves the analysis of market needs in the light of corporate objectives … But the engineer must realize that much of the input required to define the need is not technical, but rather socio-economic-geopolitical.

Therefore the engineer must appreciate those key nontechnical factors, which are significant in defining whether the results of his (or her) engineering work will fulfill a basic social, economic, or security need. With this appreciation, the engineer is better qualified to extrapolate current requirements and creatively anticipate tomorrow’s needs … The engineering method necessitates keeping open a direct link between the resources of scientific research and the state of the art available to the engineer.”

3.8 Legitimization of the Systems-Engineering Approach to “R&D” for Competitiveness: Recognizing Needs-Driven/Market-Focused Engineering Innovation vs. Science-Driven

The traditional research-driven model for engineering innovation (science-driven) has undergone substantial change and the major source for the generation of new engineering innovation has changed. As the OECD findings and the Council on Competitiveness findings indicate, technological innovation is dependent upon certain conditions for success, “best practice”, and responsible leadership. Today, both Science and Engineering (S&E) are central actors in the U.S. “R&D” system for technological innovation but they play different roles than the 1945 sequential scientific research-driven model of engineering innovation previously allowed.

Today, industry is the major source for engineering innovation, as the OECD findings and the Council on Competitiveness findings reflect; and the nation’s engineers/technology managers within industry are the primary generators, innovators, change agents, and leaders of engineering change for U.S. competitiveness. But the innovative engineering capacity for needs-driven “systematic engineering practice,” and the professional leadership capacity of engineers and technologists in U.S. industry have been largely underdeveloped because educational emphasis has been placed primarily at the graduate level on the research-driven linear model of innovation as the singular model for engineering innovation. Consequently a major “educational gap” has existed during the last three decades in the United States in the realm of innovation-based professional-oriented graduate education for the nation’s engineers and technologists in industry who are pursuing career paths that are not centered on research but are centered on the increasing professional responsibilities of “engineering practice” for the leadership of continuous systematic needs-driven engineering innovation for competitive advantage and technological progress in U.S. industry.
The interactive model of needs-driven systems-engineering innovation and directed scientific research has not just emerged or arisen abruptly. There has been growing indication for some time that the conditions for success in purposeful engineering innovation for sustained economic growth and technological competitiveness are primarily set by a purposeful systematic method of integrating directed scientific research with directed systems-engineering development, which is needs-driven, market-focused, purposeful, systematic, and continuous vs. that of periodic technical push from the basic scientific research laboratory. Previous OECD findings pointed out over thirty years ago that: “… between two-thirds and three-quarters of innovations are initially stimulated by a clear definition of market needs.” 20 Today, there is growing worldwide recognition, based on the recent OECD findings and the Council on Competitiveness findings, that fundamental change in the model of technological innovation has occurred, which is transforming the respective roles of U.S. industry, higher education, research universities, and government in stimulating technological innovation for sustained economic growth and competitiveness.

Recognition of this fundamental change in the engineering innovation process has “silently” occurred in the United States, although higher education has been slow to accept this change. Contrary to the singular emphasis on the basic research-driven linear model of innovation, which was proposed in 1945 for the U.S. civilian economy, the U.S. Department of Defense has successfully built “world class” preeminence to ensure U.S. national security since 1945, not on the basic research-driven linear model of innovation but on the integrative, concurrent, and parallel model of Science and Engineering (S&E) for needs-driven, systems-engineering innovations, and directed scientific research investigations, which were and are responsive to real/anticipated needs or threats. In essence, the United States could neither afford in the past, nor can it afford in the future, to build its national security singularly on the traditional research-driven model of engineering innovation; and neither can it afford today to build its national economic prosperity singularly on the traditional research-driven model of engineering innovation. Today both scientific research at the research universities and needs-driven “engineering practice” for creative technology development and innovation in industry are needed to ensure both scientific progress and engineering progress for U.S. technological competitiveness.

In examining the roles that needs-driven directed systems-engineering development vs. undirected basic research play, the U.S. Department of Defense conducted a major technology management study, Project Hindsight, to determine the contributions that the needs-driven, systems-engineering development approach and the sequential research-driven model of innovation had on the technological development of major defense systems since 1945. 21 The study indicated that, of the key contributions to defense systems since 1945, undirected basic research contributed 0.3%, directed scientific research 8.7%, and needs-driven creative engineering development contributed 91%. Of this work, 49% came from industry, 39% came from Department of Defense government laboratories, 9% came from the universities, and 3% from other agencies.

3.9 Lessons Learned: Coupling Directed Research for Scientific Investigations With Needs-Driven Systems-Engineering Development for Purposeful Technology Innovation
Today, the U.S. Department of Defense continues to allocate most of its budgeting to the engineering development phases of needs-driven creative technology development, from 6.2 funding of exploratory development, 6.3 funding of advanced development, through 6.4 funding of systems development of increasing complexity, with 6.1 funding of basic scientific research allocations playing a smaller but a vital supportive role in the U.S. defense innovation system. In parallel to the nation’s creative engineering work in innovative engineering development for defense is notably the nation’s purposefully planned systems-engineering development effort since the 1950s for manned space-flight and lunar exploration, from the early phases of exploratory conceptual engineering development through the phases of advanced systems engineering development, testing, manned flight, and operations, which linked the U.S. Science and Engineering (S&E) infrastructure as integrative but nonsequential processes, wherein directed scientific research is a vital part of the systems engineering approach to the development of needs-driven technology.

As Layton has pointed out: 22

“Inspired by Bush’s model of the relation of science to technology the Department of Defense, from 1945 to 1966, invested about $10 billion in scientific research, of which approximately one-quarter went for basic or undirected research. A growing skepticism concerning the technological values of this enormous expenditure caused the department to undertake an investigation, Project Hindsight. This study took eight years and consumed some forty man-years of time on the part of thirteen teams of scientists and engineers who analyzed the key contributions which had made possible the development of the twenty weapons systems that constituted, in large part, the core of the nation’s defense arsenal. Some 700 key contributions or “events” were isolated. They were classified as being either technological (engineering) or scientific (research). If the latter, they were further subdivided into basic (undirected research) and applied-science (directed research) events.

The preliminary results of Project Hindsight, which were released in November 1966, came as something of a bombshell to the scientific community. Of all “events”, 91 percent were technological (engineering), and only 9 percent were classed as science (research). Within the latter category 8.7 percent were applied science (directed research); only 0.3 percent were due to basic or undirected science. Predictably, the publication of these results produced a spate of indignant letters to the editors of Science. Many of these missed the point. The investigators had not sought to show that science has no influence on technology. What they did demonstrate was that the immediate, direct influence of this had been small; they showed that the traditional model of science-technology relations is in need of revision.

The results of Project Hindsight are surprising only if one assumes the validity of the perceived model of science-technology relationships. This model is not so much false as misleading. It assumes that science and technology represent different functions performed by the same community. But a fundamental fact is that they constitute different communities, each with its own goals and systems of values. … Each community has its own social controls — such as its reward system — that tend to focus the work of each on its own needs. These needs may overlap; but it would be surprising if this were a very
frequent occurrence. One would expect that in the normal case science would beget more science, and technology would lead to further technology. This is precisely the finding of Project Hindsight.

4. Technology Generation
In an Innovation-Driven, Knowledge-Based Economy

4.1 Two Primary Approaches to Sustain U.S. Technology Competitiveness:
Exploitation of Curiosity-Driven Research and Systematic Engineering Innovation

In essence, although the 1945 Report, Science—The Endless Frontier, established a compact for federal government to fund basic research at universities and recommended a singular approach and the use of the linear research-driven model (technical-push) for the generation of technological innovation, an alternative model of purposeful “engineering practice” for needs-driven creative technological innovation (needs-pull) has also evolved since 1945.

Whereas the Vannevar Bush Report concluded in 1945 that “it is truer than ever that basic research is the pacemaker of technological progress,” we know in 2001 that needs-driven, purposeful, systems-engineering innovation is also a primary pacemaker of technological progress. Thus, it is now apparent that there are two primary approaches that are used as the main drivers for U.S. technological progress. They are: a) exploitation of the results of curiosity-driven, undirected, basic scientific research when applicable to technology development; and, b) purposeful needs-driven systems-engineering innovation to deliberately meet real-world hopes, wants, and needs of people through the systematic “practice of engineering” for purposeful creative technology development, which integrates directed scientific research concurrently with the technology development process when necessary to better understand unknown phenomenon.

4.2 The New Realities for Successful Engineering Innovation:
Thinking “Out of the Box”

Therefore, based upon a better understanding of the engineering method for needs-driven systematic technological innovation, it is now apparent that the modern “practice of engineering” itself has undergone transformation and that the term technology has also been redefined. Although America’s technological competitiveness has been built in large measure on the exploitations of the “discoveries” of curiosity-driven basic scientific research, it is also evident that America’s technological competitiveness has been built in large measure on the “purposeful innovations” from systematic engineering practice, based on the American engineering method for purposeful needs-driven creative technology development which has been the backbone of America’s engineering inventiveness and innovative success in U.S. technology-based industry and mission-oriented U.S. government service, from our earliest industrial innovations, through manned space flight, and through continuous needs-driven engineering innovations to ensure the security of our country. Today, the American systems-engineering method for directed “R&D” provides the leadership methodology and foundation for America’s future engineering greatness, ingenuity, and continuing momentum for sustained economic growth, creativity, innovation, and engineering leadership in the civilian economy for the 21st century.
Today, in the U.S. Science and Engineering (S&E) innovation system, “R” (scientific research) is now performed primarily in the nation’s research universities, industrial research laboratories, and government research laboratories and “D” (creative systems-engineering development) is performed primarily in U.S. technology-based industry and mission-oriented U.S. government service. But “R” is not driving “D”. Today, as Akio Morita, former Chairman of Sony Corporation, pointed out, “D” is primarily driving “R” for needs-driven directed scientific research. And experienced engineer/technology managers within America’s technology-based industry and mission-oriented government service primarily perform the systems-engineering leadership function for the direction and integration of continuous needs-driven systematic engineering innovation with directed scientific research.

4.3 A Paradigm Shift in the Practice of Engineering: “Beyond the Engineering is Applied Science Paradigm”

Based on the Council of Competitiveness findings and the Project Hindsight findings, it is now evident that a paradigm shift in the American “practice of engineering” has also occurred since 1945, which needs to be further reinforced to stimulate U.S. technological innovation for competitiveness. Conventional wisdom, however, continues to define curiosity-driven basic scientific research as the forerunner and singular pacemaker of technology, wherein innovation is popularly defined as the “exploitation, adoption and deployment of new science-driven knowledge or the ability to manage new knowledge,” but these definitions are limiting at best and narrow in scope. Although scientific research is often a vital component during the purposeful creation and development of complex technological systems, engineering innovation is no longer viewed by world-class technology-based industry or by mission-oriented government organizations as the linear process of sequentially translating research findings or new scientific knowledge, generated by academic faculty through the scientific discovery process at research universities, into products, processes, systems and operations. Nor is engineering innovation defined any longer … “as the first application of science with commercial success.”

Today there is growing awareness that the capacity for systems-engineering leadership of continuous technological innovation, which needs to be integrated with directed scientific research at the universities, must become a core competence for “engineering practice” within U.S. industry across the nation. The “conditions for success” in continuous technological innovation per the OECD findings, the Council on Competitiveness findings, and the Project Hindsight findings clearly point to the vitally important roles that the nation’s engineers have as innovators and leaders in U.S. industry and to the importance of how we define engineering innovation, how we professionally educate the nation’s engineers for the systematic engineering practice of engineering innovation, and how we nurture the organizational culture for continuous systematic engineering innovation in industry itself. As Eric Walker, former chairman of the National Science Foundation Board, former president of the American Society for Engineering Education (ASEE), and former president emeritus of Pennsylvania State University noted: “Teaching research isn’t teaching engineering … the key idea is that engineering is a system of leadership that results in the satisfaction of human needs … The effectiveness of an engineer is measured by how well he or she satisfies a need — in other worlds, how well he or she invents and innovates.”
4.4 Redefining The Practice of Engineering:
“Beyond the Engineering is Applied Science Paradigm”

The evolving development of the new responsibilities, breadth, and intent of modern engineering practice was recognized by the 1985 National Research Council report, Engineering Education and Practice in the United States: Foundations of Our Techno-Economic Future, which noted: 25 “... Continuing scientific discovery and technology development will give further impetus to a revolution in engineering practice. With the use of new tools and methods the work of many engineers will become increasingly abstract, involving formulation of ideas and choosing among development options. Therefore engineers will need to be able to deal with problems in unfamiliar contexts, they will need to be knowledgeable about scientific advances generally, and they should understand the fundamentals of innovation.”

Thus, in order for the United States to sustain world-class competitiveness, engineering education and practice in the United States must go beyond the conventional wisdom and relationship of science and technology and go “beyond the engineering is applied science paradigm.” Today, there is growing awareness in the United States that an engineer’s professional education for innovative “engineering practice” is more than the application of science and mathematics to routine problems: it includes technical content as well as the development of “critical skills” for innovation to creatively meet real-world unmet hopes, wants, and needs that have not been effectively tackled before.

Although U.S. higher education has been slow to accept this change and continues to refer to engineering as “applied science or the stuff of science,” the paradigm shift in American “engineering practice” for innovation to meet real-world needs has not occurred abruptly or overnight. There is now sufficient evidence to indicate that the effective “practice of engineering” in U.S. industry and mission-oriented U.S. government service is, and has been for some time, based on the concurrent but nonsequential model of Science and Engineering (S&E) for the systematic creative development of meaningful, complex technological systems. But it must be reinforced. Curiosity-driven basic scientific research and purposeful “systematic engineering practice” for needs-driven creative technology development are now understood to be two very different, nonsequential and interdependent pursuits, with different missions, purposes, objectives, and methods, which yield two different results.

4.5 Engineering as a Creative Problem Solving Profession:
“Beyond the Engineering is Applied Science Paradigm”

What Schumpeter and Drucker foresaw has occurred, the model of innovation has undergone transformation, and innovation is now seen to be a purposeful systematic practice for change, which ultimately results in economic or social change. As Kanter points out: 28 “… Innovation refers to the process of bringing any new, problem-solving idea into use... Innovation is the generation, acceptance, and implementation of new ideas, process, products, or services.” Consequently, broader definitions of engineering innovation have emerged, which better characterize “engineering practice” for innovation as a purposeful systematic practice that involves creative engineering problem solving, needs finding, technical program making, technology policy making, judgment, and responsible proactive engineering leadership.
Thus, the definition and systematic practice of modern engineering innovation has broadened in scope. We can now redefine engineering from its broadest perspectives as being “a creative profession, concerned, with the combining of human, material and economic resources to meet the hopes, wants, and needs of society ... for the advancement and betterment of human welfare.” In essence, as Mel Mendelson, Director of the Graduate Program for Engineering and Production Management at Loyola Marymount University, Don Sebastian, Vice President for Technology Development at New Jersey Institute of Technology, and Gordon Brunner, Senior Vice President of Research and Development at Proctor and Gamble, have pointed out, needs-driven technological innovation can be described by three words: creative problem solving. 

In solving significant real-world problems, creative “engineering practice” for innovation is driven by a professional ethic and a professional way of thinking: creatively, analytically, experimentally, and holistically. The ultimate results of creative “engineering practice” (beginning with recognition of meaningful needs, and proceeding through the phases of conceptualization, development, testing, modifications, and continuous hard work) formulate the creation and development of new proven technology in the form of new/improved products, processes, systems, and operations. In essence what Teare, former Dean of Engineering at Carnegie Institute of Technology pointed out in the middle of the 20th century, holds true today as we embark on providing professional-oriented graduate education for world-class U.S. “engineering practice” for innovation for the 21st century: “Problem solving is the main task of the engineer, and when employed in the right way, is one of the most important activities in engineering education.”

4.6 Two Types of Knowledge Generation Required for Technology Innovation in a Knowledge-Based Economy

Because of the interdependent but nonsequential roles that Science and Engineering (S&E) play in the U.S. innovation system for competitiveness, it is now evident that there are multiple knowledge-base contributors in the U.S. Science and Engineering (S&E) enterprise, rather than one. Whereas academic scientific researchers and engineering research faculty at the nation’s research universities were previously designated as the primary actors, pacesetters, and forerunners of technological innovation, it is now evident that the nation’s major research universities are no longer the sole “knowledge generating sources” for new engineering innovations or for new engineering knowledge.

As the Council on Competitiveness findings and the Project Hindsight findings indicate, there are two vital human resource bases, which are new knowledge-base contributors in the U.S. Science and Engineering (S&E) innovation system and which are required to accelerate U.S. technological progress for innovation and competitiveness in the innovation-driven, knowledge-based world economy. They are:

1) The nation’s primary knowledge-base contributors for scientific research and scientific knowledge. Consisting of high caliber academic scientific researchers and advanced scientists who reside respectively within the nation’s research universities, industrial research laboratories, and government scientific laboratories who create new scientific knowledge through curiosity-driven basic research and directed scientific research for the generation of
new scientific knowledge that arises as an original “outcome” of phenomenon-oriented scientific research investigation.

2) The nation’s primary knowledge-base contributors for engineering-innovations and technological knowledge. Consisting of high caliber professional engineer/technology leaders who reside primarily within the nation’s technology-based industries and mission-oriented government service who conceptualize, innovate, and lead the purposeful systems-engineering development process for the continuous systematic generation of new/improved innovative technology and breakthrough innovations, which are responsive to existing/anticipated real-world human needs or industrial problems and which ultimately results in the continuous generation of new technological knowledge that arises as an original “outcome” of needs-driven creative systems-engineering development and purposeful innovation.

It is now evident that the nation’s academic research scientists (who reside primarily within the nation’s research universities) and the nation’s engineer/technology managers (who reside primarily within the nation’s technology-based industry) are two different types of creative knowledge professionals who play two different but vital roles in the U.S. Science and Engineering (S&E) innovation system. In essence, what Von Karman pointed out years ago, holds true today: “Scientists discover what is and engineers create what has never been before.”

4.7 Creation and Dissemination of New Scientific Knowledge

Thus, it is now evident that the two types of new knowledge, which are required for systematic needs-driven technological innovation, occur as the result of two distinct outcomes: a) by using the “scientific method” for phenomenon-oriented scientific investigations; and b) by using the “engineering method” for purposeful needs-driven systematic engineering innovation. In the pursuit of scientific research, new scientific knowledge generation is purposefully sought as an “ultimate outcome” by using the scientific method for both undirected curiosity-driven basic scientific research investigations and for directed scientific research investigations to gain a better understanding of phenomenon. In this pursuit, academic scientific researchers are primarily pursuing the creation of “propositional knowledge” in “discovering that” or in “knowing that” about natural phenomenon. As Sir Julian Huxley pointed out:

> “[Scientific research and inquiry] is perhaps best thought of as a process — the process of discovering, establishing, and organizing knowledge. To do this effectively, it must rely on scientific method … Scientific laws and concepts alike are organized creations of the human mind, by means of which the disorderly raw material of natural phenomena presented to crude experience is worked into orderly and manageable forms … Thus science is not only concerned with discovering facts: it is much more concerned with establishing relations between phenomena.” And as Alfred North Whitehead pointed out: “A scientific education is primarily a training in the art of observing natural phenomena, and in the knowledge and deduction of laws concerning the sequence of such phenomena.”

As Whitehead observed: A researcher doesn’t learn in order to know … a researcher learns in order to “discover.” And the “critical skills” that are required for this type of “new knowledge generation” are reflected by the importance that inquiry-based learning and the scientific method
have in the traditional educational model for research-based scientific graduate education. Consequently, a scientific education must also prepare future academic researchers to engage in learning “procedural knowledge,” that is, in “knowing how to” conduct original scientific research investigation, which is the basic educational premise for combining scientific education with scientific research simultaneously at research universities as a synergistic learning experience for the training of young researchers. In essence, the primary “outcome” of scientific research investigation is to gain a better understanding of natural phenomenon, which ultimately results in the creation of new scientific knowledge and the advancement of scientific progress.

4.8 Creation and Development of New Technological Knowledge

For innovative “engineering practice” in industry, however, both the type of new knowledge generation and the corresponding type of further graduate education that supports this systematic practice, beyond basic entry level engineering education, are quite different from that required for the graduate scientific education of young academic scientific researchers. Although relevant scientific knowledge and relevant state-of-the-art technological knowledge are employed in systematic needs-driven engineering innovation, the mechanisms for needs-driven systems-engineering, creative problem solving, and systems-engineering leadership involve much more than just the application of existing knowledge or new scientific knowledge to problems, as the sequential research-driven model of engineering innovation implies.

Engineers do not apply new/improved technology: they “conceptualize, create, and develop” new/improved proven technology, which results as an outcome of their innovative capacity by using the engineering method to creatively solve unmet real-world industrial problems and human needs. Based on a better understanding of the mechanisms of the systems-engineering approach for creative engineering problem solving for innovation, we now know that new scientific knowledge is deliberately obtained and used as a contributor in the development of complex technological systems rather than as the initiator of engineering innovation. It is obtained through needs-driven, directed scientific research to gain a fuller understanding of unknown phenomenon that is anticipated or that arises during the course of technology development. The development of new/improved technology, however, is deliberately obtained through directed engineering creativity and leadership by using the purposeful, needs-driven engineering method for creative problem solving, wherein both new/improved technology and new technological knowledge result as outcomes from this integrative creative engineering process.

Whereas both scientific researchers and creative engineers produce “new knowledge,” the types of new knowledge are quite different, as are their respective methods for new knowledge generation. Whereas scientists “discover” and create new scientific knowledge, engineers “invent” and create new engineering knowledge (technological knowledge) by purposeful design and responsible engineering leadership. The formal knowledge that engineers use at the start of the engineering process for the systematic invention, development, and design of new/improved technology is a combination of both scientific knowledge and engineering knowledge (technological knowledge) but innovative engineers go beyond this early knowledge stage through their innovative capacity for the conceptualization, invention, and design of new “ideas
and concepts,” which are required in creatively and effectively solving real-world industrial problems and in meeting meaningful real-world human needs.

As Ferguson points out: “To design is to invent”… Design and invention lie along a continuum that ranges from the obvious to the inspired, from design routines that involve a minimum of intellectual engagement to original, fundamental inventions that change forever our way of tackling certain problems.” As Ferguson notes: “The philosopher Carl Mitcham gives design and invention their proper places in the scheme of things by observing that “invention cause things to come into existence from ideas, makes world conform to thought; whereas science, by deriving ideas from observation, makes thought conform to existence.” Whereas academic researchers are directly pursuing the creation of new scientific knowledge, engineers are directly pursuing the creation and development of “new techniques and innovations” to meet real-world needs, which ultimately results as an outcome in new engineering knowledge (technological knowledge) and in advancements to the new state-of-the-art of technological knowledge.

Thus, in innovative “engineering practice” for the systematic development and innovation of new/improved technology, experienced engineers in industry not only learn the state-of-the-art of existing technological knowledge that is specifically relevant to their field, but they learn from previous engineering design concepts on-site in industry, and go beyond this knowledge by purposefully creating and developing “new techniques” (technology) to advance the state-of-the-art of their corporate technology for competitive advantage. The ultimate “outcome” of this creative engineering work is “new proven technological knowledge” in the form of new products, processes, systems and operations for competitive advantage.

5. The Need for Integrative Transformation in the U.S. Innovation System
In Reshaping Graduate Professional Education for Innovative Practice in Industry
And Directed Scientific Research to Accelerate the Pace of U.S. Competitiveness

5.1 Strengthening The Pace of U.S. Technological Innovation

There is growing national awareness that the U.S. Science and Engineering (S&E) innovation system must be substantially reinforced to better reflect the transformation of the systematic engineering innovation process itself and to better reflect the human resource development needs of the nation’s engineers who lead the technology innovation process for U.S. competitiveness. Thus, it is now understood that new university-industry-government partnerships which can make integrative improvements by linking relevant advanced professional education and directed scientific research together to the educational needs of engineers and to the on-going systematic engineering innovation process in industry can be a formidable mainstay for America’s continued technological progress for sustained competitive advantage over the long term. The systems-engineering approach which links directed scientific research with needs-driven engineering innovation has “stood the test of time” and it is now time for an integrative transformation in the U.S. Science and Engineering (S&E) innovation system which reflects the need for combined improvement in higher education by reshaping graduate professional education for engineering innovation in industry and by better focusing directed university scientific research to meet industrial needs to enhance U.S. competitiveness. This is a two-
pronged approach in the nation’s interest, with multiple and significant outcomes, which impacts America’s future technological preeminence for sustained industrial competitiveness.

5.2 Lessons Learned

It is now evident that the linear research-driven model of engineering innovation is neither adequate nor sufficient to serve as the foundation model for systematic engineering innovation in industry nor upon which to build a curricula of advanced studies for the further advanced professional education of creative “practicing engineers” who develop U.S. competitive technology in industry. The lessons learned from the OECD findings, the Council on Competitiveness findings, the Project Hindsight findings, and from the known characteristics of “innovation best practice” apply systematically to the need for an integrative transformation which reshapes graduate professional education for “practicing engineers” in industry, further develops core innovative engineering capacity in U.S. industry, and better links directed university scientific research efforts to the needs of industry in order to enhance U.S. technological competitiveness for the long-term.

The lessons learned are twelve fold:

- **First, a transformation of the model of engineering innovation itself has occurred and a new model of engineering innovation, based on conditions for success, has emerged.**

As Sanders and Brown have pointed out: The great discovery of our age is that technological innovation need not be haphazard. Industry and government have developed a new concept of planned and systematized innovation, founded on vastly expanded scientific and engineering efforts. Today, engineering innovation is primarily a purposeful, deliberate needs-driven “systematic engineering practice,” which recognizes the integrative but nonlinear roles that Science and Engineering (S&E) play in technological innovation, and which integrates needs-driven creative engineering development and directed scientific research for scientific investigation of unknown phenomenon that arise during the development of technology. Today, it is evident that university scientific research and needs-driven, market-focused, engineering in industry are two different but vital components of the U.S. technological innovation system. But what’s been missing in the U.S. innovation system has been high quality engineering leadership education, which promotes the further growth, learning, and development of engineers for the “practice” of engineering innovation.

It is now evident that what drives undirected fundamental scientific research discoveries is curiosity; what drives directed scientific research discoveries is the need to gain a better understanding of unknown phenomenon that occurs or is anticipated to occur in complex technology development projects (the outcome of which is new scientific knowledge and a better understanding of phenomenon); and what drives engineering innovation are real-world needs. Although many research-oriented faculty think that directed scientific research and directed engineering development are the same, they are not. As Layton has pointed out: directed scientific research and directed creative engineering development are two different activities, with different cultures, missions, goals, and value systems.
Second, systematic engineering innovation starts with user’s needs as the driving force for creative technological innovation.

The professional engineering wisdom and vision to recognize, understand, and to create effective solutions to meet real world needs accelerates technological progress. As Isenson reports: 32 The first conclusion of the Project Hindsight study is that real needs drive the pace of accelerated technological growth and that technological progress in wartime or peacetime depends upon a flow of “new ideas and ‘concepts’” to create effective solutions to real-world human needs. The importance of market orientation and recognition of real needs, as the primary driver for successful engineering innovation and technology development, is paramount.

Based on a better understanding of the mechanisms of using a systems approach to engineering innovation for creative engineering problem solving, we now know that directed scientific research is deliberately used as a contributor in the development of needs-driven technology rather than as the initiator of systematic technological innovation. In this process needs-driven directed scientific research is used to gain a better understanding of unknown phenomenon that is anticipated or arises during the course of technology development. As Walker, pointed out in years past hold true today: “The key idea is that engineering is a system of leadership that results in the satisfaction of human needs.”

Third, there are two types of creative knowledge bases that need to be continuously created and domestically sustained in order for U.S. technological innovation to be fully realized for economic competitiveness in the 21st century.

We now know that there are two different types of new knowledge that arise from, and are expected as outcomes of, needs-driven purposeful systematic technological innovation. They are: 1) the continuous creation of new scientific knowledge, which arises as an outcome of the scientific method of “discovery” by scientific researchers in the nation’s research universities, industrial laboratories, and government research laboratories; and 2) the continuous creation of new engineering knowledge (technology), which arises as an ultimate outcome of the engineering method for the purposeful and systematic “conceptualization”, design, development, and innovation of new/improved technology in the form of products, processes, systems and operations by practicing engineers in the nation’s industry and mission-oriented government service. These two types of new knowledge are obtained by the integrative use of the systems-engineering method and the scientific research method to meet real-world needs. Although the linear research-driven model for engineering innovation placed singular emphasis on new scientific knowledge, generated at the nation’s top research universities by academic research faculty, as the primary driver for engineering innovation, this has proven neither adequate nor sufficient in today’s competitive economy.

Fourth, industry is the nation’s primary source for U.S. engineering innovation wherein the primary change agents and leaders for the creation, development, and innovation of new/improved technology are the nation’s practicing engineers/technology leaders within industry.
Whereas the primary source for the nation’s scientific progress in curiosity-driven fundamental research resides within the nation’s major research universities, the primary source for the nation’s engineering progress and innovative engineering capacity for needs-driven creative technology development resides within the nation’s industries, wherein the primary generators, innovators, and leaders of new/improved technology are the nation’s innovative practicing engineers in U.S. industry.

However, there is systemic indication that U.S. engineers are too often underutilized and too often underdeveloped (with notable exceptions) in U.S. industry and in America’s higher education system. Although the United States is the most highly developed scientific nation in the global economy, its human resources in engineering practice are one of the most underdeveloped resources in the world. As Bohn points out: 33 Too many of the nation’s engineers find themselves in poorly led organizations where they are chronically “fighting fires” and performing “quick and dirty patching” to provide quick fix solutions — rather than being able to get at the source of the problems/needs for more effective long-term systematic engineering development of products, processes, systems, and operations for continuous technological improvement.

- **Fifth, U.S. industry must rebuild its innovative engineering capacity for systematic creative technology development as a core corporate competency across the nation.**

Innovative industries are now recognizing that in order to be competitive as technological leaders, they must foster innovative engineering capacity on a continuous basis, not only to compete but to sustain long-term U.S. economic growth in today’s knowledge-based, innovation-driven economy as a matter of survival.

Today, effective technological innovation is closely linked to continuous systematic incremental improvements and systematic breakthrough innovations, which are driven by market needs and production requirements. New products, new processes, new industries, and more jobs require a purposeful, planned engineering development process, creativity, technical competence, and an innovation ethic for continuous improvement, breakthrough development, with ethical, legal, economic, and environmental responsibility. As Ben Rich, the former head of Lockheed’s engineering development group for the Stealth, stated: 34 “Any company whose fortune depends on developing new technologies should have an engineering development group (Skunk Works) in operation, which will always demand a strong leader and a work environment dominated by highly motivated employees … “Given those two key ingredients, the engineering development group will endure and remain unrivaled for advancing future technology.”

- **Sixth, the U.S. thrust for the continuous creation of new scientific knowledge (from scientific research) and for the continuous creation of new technological knowledge (from engineering) requires that two equally important but different types of teaching and graduate education be created, sustained, and continually nurtured.**

Both academic scientific researchers in the nation’s research universities and advanced practicing engineers in U.S. industry are vitally important for the nation’s sustained technological competitiveness. However, their respective graduate educations can neither be
perceived any longer as the same, nor as a by-product of a singular science policy, which perceives scientific research as the primary driver for engineering innovation. Today, scientific research and engineering play interdependent roles in the U.S. Science and Engineering (S&E) innovation system for competitiveness: and modern graduate education must reflect this change in the engineering innovation process itself.

Although relevant scientific knowledge and relevant state-of-the-art technological knowledge are employed in systematic engineering innovation, the mechanisms of engineering innovation for creative engineering problem solving involve much more than just the application of existing knowledge or new knowledge to problems — as the erroneous linear research-driven model implies. Innovative engineers in competitive industry do not apply new/improved technology: they “conceptualized, create, and develop” new/improved technology, as a purposeful outcome of their innovative capacity to creatively solve unmet real-world needs and industrial problems. Whereas research universities are emphasizing the hiring of research-oriented faculty more than ever for national areas of directed scientific research specialization and to build research-based graduate education programs, it is also time for universities to allow room for the development of professional-oriented innovation-based graduate programs for the leadership of engineering innovation — serving the vital national interests of enhancing the practice of engineering in industry that is the foundation of the nation’s techno-economic future.

- Seventh, the recruitment, retention, and further professional development of innovative engineer-leaders in U.S. industry are the backbone of America’s strength for competitive advantage in engineering innovation.

The ever-increasing influence and rapid advance of worldwide needs-driven technology development demands a highly skilled and responsible creative practicing profession of experienced engineering leaders in U.S. industry. The quality of U.S. engineers and their further post-baccalaureate professional development affects the quality of our lives and U.S. competitiveness. As it is with the pace of high-quality scientific research for scientific progress, and the nation’s dependence on the educational quality of U.S. academic scientific researchers for fundamental and directed scientific research, the pace of U.S. engineering progress is dependent upon the quality of the nation’s engineers who lead the process for innovative technological change and the quality, and relevance, of their further post-baccalaureate professional education in combination with progressive engineering experience that prepares them for engineering leadership responsibilities.

As Isenson notes: 35 “In examining the personal histories of scientists and engineers (Project Hindsight) who had contributed most heavily to the new technology of use to the Department of Defense, the employment stability of these individuals stood out as a most significant factor. Moreover, it was found that the most effective scientist or engineer — in terms of the probability that he (or she) will come up with something that will be profitable to the organization — is one who has been in the company for a number of years. The modal point on the distribution curve displaying length of employment against probability of making a useful contribution occurs at between seven and nine years of employment. Clearly, if the professional turn-over rate exceeds 10% to 15% per year, it will be most unlikely that the peak performance of the laboratory will ever be achieved.”
Eighth, engineers need to be promoted into management and leadership positions of technological responsibility for U.S. industry’s long-term competitive growth.

As Kingston noted: 36 “Reality endorses Schumpeter’s dictum that successful innovation is a question of leadership.” It is now evident that the responsible leadership of purposeful, needs-driven, systematic engineering innovation in U.S. industry requires leadership by experienced, full-fledged, responsible engineer/technology leaders who have an understanding of their field of technology, who have an understanding of the systematic engineering methodology for purposeful needs-driven technological innovation, and who have the vision, innovative capacity, technical knowledge, and multi-dimensional skills to lead meaningful technological change for sustained economic growth, competitiveness, and improvement of the human condition.

Engineering leadership plays a central role in the continuous development of innovative technological capability in U.S. industry for economic growth, improvement in the quality of life, and ensuring our national security.

Engineering leadership is a unique practice of increasingly higher level engineering responsibility, which includes the entrepreneurial functions of needs finding, technical program making, technology policy making, and continuous vision setting within corporate objectives to build, to nurture, and to sustain the innovative capacity of U.S. technology-based industry. The continuous renewal of the nation’s capacity for innovative engineering leadership in industry, requires a continual educational supply of entry level engineers into industry and the educational provision for an integrative plan of post-baccalaureate professional education, which integrates advanced professional studies with progressive engineering experience in industry in a manner that will support the engineer’s further professional growth, learning, and development, after entry, for increasing technology leadership responsibility. What the OECD pointed out over thirty years ago, holds true today: “The increasing scope of technical change suggests an important requirement for educational policy, namely, to train not only the creators of new science and technology, but also the leaders of technological change… however, one must recognized that the long time-spans and uncertainty associated with technological innovation often render conventional management techniques inapplicable.”

Ninth, the conditions for success in engineering innovation require the creation of working organizational environments and innovation-learning cultures within industry itself, which encourages creative engineering problem-solving, technological development, and innovation to flourish continuously.

Because of the transformation of the model of the engineering innovation processes itself, competitive industry must engage in the full use of techniques, which are useful in developing needs-driven creative engineering problem solving, innovative engineering capacity, needs-finding, technical program making, and strategic technology policy making with long-range vision. This requires supportive professional-oriented graduate education to develop engineer-leaders and group organizational development, wherein technology development itself becomes a continuous professional learning process that is accelerated in an innovative-learning culture by collaborative creativity. As Bohn points out, chronic fire fighting and patching is destructive: “…Patching not only takes more time than systematic problem solving, it also fails to fix problems. The really bad news is that under fire-fighting conditions, pressures push engineers to
solve problems not just inefficiently but badly. They don’t work on a problem long enough to uncover its root cause — they just make a gut-feel diagnosis. Then, instead of testing their hypothetical diagnosis offline, they introduce a hasty change in the process. And if the quick fix doesn’t solve the problem completely (it is usually unclear whether it helped or not), they leave it in place and try another solution. They don’t solve the problem because they don’t take the time to approach it systematically.”

It’s not easy but what’s required is to transform this typical type of organizational culture by building the innovative capacity for creative engineering problem solving and innovation into the mainstream of the organizational culture through professional-oriented graduate education for effective engineering leadership in synergism with on-going technology innovation in industry. As Kanter notes: “…internal investment is what creates the climate for the innovations allowing companies to stay ahead in a changing environment. The potential exists for an American corporate Renaissance, with its implied return to greatness … and innovation is the key … Individuals can make a difference, but they need the tools and the opportunity to use them. They need to work in settings where they are valued and supported, their intelligence given a chance to blossom. They need to have the power to be able to take the initiative to innovate. Whether the promise of this corporate Renaissance is fulfilled depends on how fully corporate leaders understand this need and decide to act on it. It depends on whether we can come to embrace change, to see it as an opportunity, and thus to stimulate the people in our organizations to take action to master it … as a nation, we can no longer afford to do otherwise.”

- Tenth, universities across the nation need to engage in a national collaborative alliance with industry in reshaping professional-oriented graduate engineering education, which better reflects the transformation of the engineering innovation process itself and which better meets the relevant professional-oriented graduate education needs of engineers who lead the process for continuous systematic technological innovation in industry.

It is now evident that a major “gap” exists in professional-oriented graduate education for the nation’s engineer-leaders in industry, which must be filled to better provide the professional engineering dimensions for creative engineering problem solving, strategic technical program making, and technology policy making to enhance engineering leadership capacity for U.S. technological competitiveness. Implementation of this needed educational transformation, however, can neither fully occur by universities acting alone nor without the direct input of U.S. industry and the practicing engineering profession?

A national effort for collaborative educational advancement in professional education is needed. The question is straightforward: a) If the future economic growth of the nation is dependent upon innovative engineering competitiveness, then the propensity of the nation’s innovative capacity for engineering innovation is continuously dependent upon the further professional growth of the nation’s engineers in industry beyond entry level; and b) The further professional growth of emerging and experienced engineering leaders is dependent upon the graduate professional educational capacity of the nation’s regional and major research universities to provide high-quality professional education that continues the fullest post-baccalaureate professional development of the nation’s creative engineering leadership talent in industry. The United States can neither afford any longer not to fully develop its domestic engineering talent in
industry for the leadership of engineering innovation, if it wants to fully compete in today’s new economy, nor can the nation afford any longer to treat innovative engineering practice in industry as a byproduct and follow-on to academic scientific research. The “stakes are too high” for America not to rebuild its competitive edge in U.S. industry through engineering.

Eleventh, U.S. industry must form closer working partnerships and new engagement mechanisms with universities across the nation that better integrate the university ingredients of directed scientific research and advanced professional education for engineers with the technological innovation process in industry.

U.S. industry needs to partner with regional universities across the nation in order to more fully couple the capacity development of its core engineering innovation capability with the directed scientific research capabilities and graduate professional educational capabilities of universities in order to take a new integrative systems approach to directed academic scientific research and professional-oriented graduate engineering education to enhance U.S. competitiveness. The investment by industry in new university-industry mechanisms for sustained industrial research partnerships for high-quality directed scientific research and for high-quality post-baccalaureate graduate professional education for its engineers is not philanthropic but makes good business sense.

The universities provide the missing ingredients that industry does not have. The universities provide a continuing pipeline for engineering creativity and innovation by serving as the source for new entry-level creative engineering talent; and by serving as the educational catalyst for the advanced professional development of these creative engineers after entry for increasing responsible technology leadership positions. In essence, the nation’s engineering schools now have the unique opportunity and the responsibility for educational leadership to implement needed educational reform for renewal of their mission in professional education, which provides a vehicle to continuously stimulate U.S. technological innovation and the further educational development of America’s engineering creativity, inventiveness, technology leadership, and innovative capacity — in partnership with U.S. industry.

Twelfth, state governments, federal government, industry, and foundations must serve as a collective catalyst for this transformation in graduate professional engineering education across the nation, which will strengthen the innovative engineering capacity and technology competitiveness of U.S. industry for sustained growth in the new economy.

State governments, federal government, industry, and foundations have a proper role to play in supporting regional and national economic development through the advancement of graduate professional education for engineering practice that better develops the U.S. domestic engineering base in industry for real-world needs-driven engineering innovation.

Whereas, U.S. research universities, through state and federal government funding, primarily bear the academic tuition and salary burden for the graduate scientific research education of both foreign and domestic graduate research students, U.S. industry must primarily bear the academic tuition and salary burden for the further advanced professional education of its engineers through this needed educational transformation. State governments, federal government, and industry,
however, have the responsibility to ensure that the provision for the advancement in innovation-based, professional-oriented graduate education for the nation’s engineers occurs, which will enable engineering innovation in all technologies to flourish. Universities have the equal responsibility to allow this needed reform in graduate profession education to occur, not only to enrich their academic scientific research mission but to enrich their mission for high-quality professional education and outreach engagement with industry which has too often been neglected.

As the Kellogg Commission report, “On The Future of State and Land-Grant Universities,” has pointed out: “Our tried-and-true formula of teaching, research, and service no longer serves adequately as a statement of our mission and objectives. The growing democratization of higher education, the greater capacity of today’s students to shape and guide their own learning, and the burgeoning demands of the modern world require us to think, instead, of learning, discovery, and engagement.” The needed educational reform for the advancement of graduate professional education for the nation’s engineers in industry serves to fulfill the new integrative mission of universities and their new engagement mechanisms with U.S. industry to advance U.S. economic competitiveness and the quality of life through the combination of providing advancement in graduate professional education, directed scientific research, and needs-driven engineering innovation in a synergistic manner.

6. Reflections on the Need to Rethink the Advanced Education of Engineers
As Innovators and Leaders in Stimulating U.S. Technology Innovation for Competitiveness

6.1 Educating the Engineer as a Professional

The changes that are needed in reshaping graduate professional education for engineers in industry are significantly broader and deeper than previously recognized by the academic community and deal with issues at the very core of the professional foundations of “engineering practice” and technology leadership for the 21st century. Previous changes in engineering education during the last several decades have primarily been incremental changes largely related to undergraduate education and to graduate education for academic research.

The present need for educational change is transformational because of the transformation in the process of “engineering practice” itself for needs-driven engineering innovation in industry. To accomplish this change, a national transformation needs to be made in reshaping graduate professional education that better supports the further career-long learning, growth, and professional development of “practicing engineers” beyond entry level in U.S. industry for systematic technological innovation and creative industrial practice.

As Saul Fenster, President of the New Jersey Institute of Technology, has pointed out: “There are important forces driving changes in the engineering curriculum. These include (1) global economics, (2) rapid diffusion of information, (3) technology, (4) the convergence of disciplines, and (5) the need for the education of the complete professionalism for today’s field. Engineering education must occur in context of international changes, and in consideration of the role of the engineer as a systems integrator, leader, manager, entrepreneur, and innovator. Increasingly, the engineer plays a key role in responding to the rising aspirations of people everywhere for a better
life. This greatly enhances the professional components of the engineer’s role. … The context for engineering education includes economic and social factors, as well as changes in technology and the magnitude of the complexity and multidimensionality of the problems to be solved. These result in the need to significantly broaden the education of the engineer, and balancing achievement of diverse outcomes while maintaining a reasonable course of study.”

6.2 Driving Forces for Change in Reshaping Graduate Professional Education For Engineers in Industry in the Context of “Engineering Practice” for Technology Innovation

It would seem a tautology, as President Fenster has pointed out, that the role of the engineer in the year 2000 and beyond and the professional engineering curriculum for the practice of innovative engineering ought to be in harmony. Today, however, they are not. Whereas, U.S. scientific education for graduate academic research is well established, is government funded, and is recognized worldwide as preeminent, the need for educational transformation today is in reshaping U.S. graduate professional education for industrial practice and the engineering leadership of continuous creative technology development in industry. Toward this aim, the rethinking of further advanced professional education that extends the professional development of graduate engineers in industry beyond the rudiments of entry level undergraduate baccalaureate education and that purposefully supports the encompassing role of the engineer as an innovative professional who leads the systematic practice of needs-driven creative technology development in industry requires a vision and a new way of thinking that must go beyond the conventional wisdom of providing professional education as the sequential “transmission of knowledge, acquisition of knowledge, and then practice for application” or as a “byproduct of scientific research.”

In the past, and still today, however, the singular emphasis on the linear research-driven model of engineering has placed the education of the nation’s engineers by default primarily in the passive category as just users andappers of “new scientific knowledge,” wherein as Walker pointed out, “Too many faculty members sincerely believe that research is engineering.” It isn’t. The singular emphasis on research as the driving force for engineering innovation has left little room for the development of the practicing engineer’s performative knowledge i.e., “knowing how to do” innovative engineering that is responsive to real-world needs or for the development of the engineer’s “critical skills” and professional dimensions for industrial creativity, invention, innovation, creative problem solving, strategic program making, and technology policy making which are needed in advanced “engineering practice” for the responsible engineering leadership of needs-driven systematic engineering innovation in industry.

Today, however, engineers play more proactive roles and engage in the responsible leadership of needs-driven systematic engineering innovation, in which they are both users of “new scientific knowledge” and also creators of new “engineering knowledge” i.e., technological knowledge, which occurs as an outcome from using the engineering method for the purposeful advancement of the state-of-the-art of technology in the form of new/improved products, processes, systems, and operations to meet the real-world needs of people. Because of the singular emphasis on research-oriented graduate education at most of the nation’s universities, too many schools of engineering in the United States have fallen behind actual real-world innovative practice in industry and have neglected their professional mission and educational balance in promoting
professional education programs that complement research in the context of “engineering practice” for real-world engineering innovation which is performed in industry. As Walker pointed out: This neglect has been a significant contributing factor for the past three decades to America’s decline in its competitive posture in innovative technology and productivity worldwide. It is now evident that real change is needed at the nation’s universities to improve U.S. innovative engineering capacity at the graduate level. And there are now indications throughout the nation of the direction that this change must take.

6.3 Basic Themes for Reshaping Graduate Professional Education for Engineers in the Context Of “Engineering Practice” for the Development of Innovative Technology in U.S. Industry

Broad changes in the way engineering education is done are required in order to build a sustaining infrastructure within American engineering education that better supports the context in which innovative professional engineering practice is performed in U.S. industry. The development and implementation of graduate professional education for “practicing engineers” in U.S. industry must take on several new dimensions in order to be more directly supportive of the practicing engineer’s creative work in the engineering innovation process itself. Today, because of new ways of teaching and because of technology itself, we have the capability to make a significant advancement in the United States in the realm of further coherent graduate professional education, beyond entry level, for the nation’s innovative engineers in industry, wherein graduate professional education and the engineer’s actual work in creative technology development can now form a concurrent synergistic union for continuous growth throughout his or her professional career in creative “engineering practice.”

To accomplish significant and sustainable change, planned educational transformation needs to be made by a collaborative alliance of innovative universities and partnering industries across the nation to reshape graduate professional education for U.S. engineers in a manner that also serves as catalyst to continuously stimulate U.S. technological innovation for sustained U.S. competitiveness. There are basic themes in setting a shared vision and purpose for this unique collaborative alliance between universities and partnering industries to develop and sustain first-rate graduate professional education for engineer/technology leaders in U.S. industry to enhance competitiveness. They are:

- **First, to provide high-quality graduate professional education in the professional context that supports innovative “engineering practice” and technology leadership in U.S. industry in order to continuously enhance and sustain U.S. technological innovation for competitiveness and to improve the standard of living through systematic engineering innovation and creative industrial practice.**

- **Second, to provide high-quality graduate professional education in the professional context that fosters the career-long learning, growth, and innovative capacity of engineers, beyond their entry level proficiency, toward their fullest creative, innovative, and leadership potential in the practice of engineering in order to more fully develop engineering professionals who will be leaders in creating and designing the technologies of the 21st century.**
• Third, to provide new integrative mechanisms that build stronger engagement relationships between regional/research universities and their constituent industries by building an integrative transformation between graduate professional education, directed scientific research, and on-going engineering innovation projects within regional technology-based industry that supports the synergism of providing advanced professional education for “engineering practice” concurrently with on-going needs-driven technology development to continuously develop innovative technology in industry and engineering leaders simultaneously.

• Fourth, to build a sustaining educational transformation across the United States that is supported by regional industry, foundations, and government, in representative regions: to continuously stimulate significant technological innovation across the nation; to enhance the creative, innovative, and leadership capacity of the nation’s engineers for technological competitiveness, and; to build advanced professional education for excellence in “engineering practice” into the fabric and infrastructure of American universities as a sustaining feature of U.S. higher education.

• Fifth, to maintain a shared vision and focus on the collective impact that this unique collaborative alliance between higher education and industry can make across the nation: in continuously stimulating needs-driven engineering innovation within technology-based industry: in continuously enhancing economic development, technological progress, and U.S. competitiveness by strengthening systemic innovative capacity in the U.S. Science and Engineering (S&E) innovation system, and; in sustaining a multiplicity of new technology innovation groups within participating industry, universities, and statewide regions across the nation by linking graduate professional education and directed university research to the technology development needs of industry.

6.4 Framework for the Development of Context-Based Graduate Professional Education for “Engineering Practice” in U.S. Industry

Although America’s graduate education infrastructure for scientific research is the best in the world and prepares young investigators to do original research, a professional educational “gap” currently exists in America’s engineering education infrastructure for the further in-service graduate professional education for the nation’s engineering base in industry. To meet the challenge for transformation, we must set new directions for a new kind of professional-oriented graduate education that extends beyond entry level proficiency for the further professional development of the nation’s engineers in industry, based on substantive criteria for educational change in the context of engineering. Designing the conceptual framework for a new type of context-based professional-oriented program of advanced graduate education for engineers in industry requires a clear definition of aims, method, program, administration, and a redefinition of professional education itself.

Today, there is growing national awareness that the educational foundations for the development and implementation of first-rate advance professional education that extends the opportunity for the further growth, learning, and professional development of competent engineers beyond the basic entry level of engineering proficiency/responsibility is multifaceted and multidimensional.
The conceptual framework for this transformation in context-based graduate professional education includes fifteen foundational criteria. They are:

CONTEXT 1:
Reshaping Graduate Education for U.S. Engineers in the Context of The Aims of Graduate Professional Education for Engineers in Industry

The overriding *Aims* of providing a new type of high-quality graduate professional education for engineers and technologists in industry, which complements scientific research, are set in the educational context of providing opportunity for the engineer’s further learning, development, and growth concurrently with meaningful innovative “engineering practice” in industry. As Dewey noted, in a democratic society the aim of education is to enable individuals to continue their education for growth.”

Correspondingly, whereas the primary aim of basic (pre-service) undergraduate education for engineers is to prepare young men and women for entry into “engineering practice,” the primary *Aim* of advanced (in-service) graduate professional education for graduate engineers is to provide opportunity that fosters continuous in-service growth and professional development of the emerging and experienced engineer-leader after entry into “engineering practice” toward his or her fullest creative, innovative, and leadership potential in the creative practice of engineering.

CONTEXT 2:
Reshaping Graduate Professional Education for U.S. Engineers in the Context of Lifelong Learning, Growth, and Development Beyond Entry Level as a Process of Professional Maturation and Intrinsic Creative Development for Leadership in “Engineering Practice”

The concept of professional education has changed. Today, advanced professional education extends beyond the simplistic concept of the transmission and acquisition of knowledge from teacher to student (even though new knowledge is vital in the technological innovation process and innovative engineers constantly seek it out). But today, professional education can no longer be considered “essentially or only a learning process.” It is also a developmental process of intrinsic creative human potential and character development, which must not terminate at entry level.

The educational context for providing high-quality graduate professional education that fosters the further in-service learning, development, and growth of practicing engineers and technologists in industry, beyond entry level, includes several educational premises which are quite different from those required for either pre-service entry level undergraduate engineering education or for research-based graduate education for scientific research because the missions, aims, and objectives of these different types of education are different as are the objectives and aims of the participants. As Fenster has pointed out, it would seem a tautology that the role of the engineer and the professional education of engineers for “engineering practice” ought to be in harmony: and, it would also seem a tautology that undergraduate engineering education serves to start this educative process as a *basic* foundation for further professional growth and *not* to terminate it.
Nevertheless, although most forms of traditional professional education prepare students for entry into the professions, they unfortunately usually terminate at this level. As Schein points out:43

“Most professional education makes very few provisions for a smooth transition to professional practice or for the continuing education of practitioners. Once the student has completed his professional education, he is more or less on his own to find the right kind of job and to keep himself up to date by whatever means he can find. He receives some help from professional associations through seminars, meetings, publications, and other professional activities, but he generally loses touch with his school except as an alumnus who is expected to help the school rather than vice versa.”

Today, in order to enhance U.S. competitiveness, the nation must unlock the constraints of existing engineering education and go beyond the limitations of terminal baccalaureate education for creative “engineering practice” in industry. Most of the continuing learning in the professions is depicted by a “hodgepodge” and a cafeteria style of continuing education courses and it is apparent that a lack of coherent program planning and educational philosophy exists. As Houle pointed out:44 “Too few professional continue to learn throughout their lives, and the opportunities provided to aid and encourage them to do so are far less abundant than they should be.” An engineer’s professional development extends beyond the baccalaureate and the United States must unlock the creative and innovative potential of this underdeveloped resource by providing the nation’s graduate engineers and technology leaders the professional educational opportunity to continue to grow beyond entry level engineering proficiency in industry by providing specifically designed high-quality graduate professional education that is responsive to the progressive dimensions and responsibilities of modern “engineering practice” in U.S. industry.

There is growing national awareness that there is much more to the education of an engineer who is pursuing a professional career in “engineering practice” in industry than simply the one-time transmission and acquisition of knowledge from “teacher to student,” which is done in the early years of an engineer’s education, as the conventional view of engineering education portrays. It is now acknowledged that we cannot accomplish everything in 4 years of pre-service undergraduate engineering education or even in 5 year programs because the professional maturation process for the further development of engineering leaders in industry is an ongoing process of lifelong learning, development, and creative growth which includes the realms of actual progressive engineering experience and actual creative performance in the tasks of real-world technology development for innovation. In this process, pre-service undergraduate engineering education serves as the basic educational foundation for this lifetime journey.

As Walker pointed out: As long ago as 1930, the Wickenden Report recommended that a further period of study be required beyond the first entry level into industry. As the Wickenden Report noted: The engineer’s further professional growth requires the combination of progressive engineering experience and further advanced professional studies beyond the baccalaureate, which involves a process of professional maturation from the entry level of engineering practice of known-laws and data through the progressive stages of developing technical judgment and value judgment extending to the highest proficiency levels of the practicing profession.
Nevertheless, although America’s graduate education infrastructure for scientific research is the best in the world and prepares young investigators to do original research, a professional educational “gap” exists in the U.S. Science and Engineering (S&E) infrastructure, beyond entry level in “engineering practice,” for the further in-service graduate professional education of the nation’s engineers and technology leadership base in industry who are responsible for competitive technology development and innovation as a core competency in U.S. industry.

CONTEXT 3:
Reshaping Graduate Professional Education for U.S. Engineers in the Context of The Stages of Growth, Responsibility Levels, and Proficiency Levels in “Engineering Practice”

It is now recognized that filling the existing educational “gap” by providing high-quality graduate professional education that promotes the further growth of engineers and technologists in industry beyond entry level proficiency can make a significant impact in enhancing U.S. innovative capacity and in stimulating new engineering innovations in industry. The “gap” in professional education for the nation’s engineers persists largely as a lingering result of the singular emphasis on research-oriented graduate education in U.S. higher education and the general lack of awareness of the progressive levels of leadership proficiencies and responsibilities that engineers must acquire throughout their professional careers in industry or government service. As the 1995 NRC Reshaping Report suggests: 45 The graduate education of U.S. engineers and technologists is largely a byproduct of research-based graduate education and the linear research-driven model of innovation.

The needed educational transformation, which is required to develop a new complementary type model of high-quality in-service graduate professional education for the nation’s engineers is based on the reality that most of the U.S. graduates in engineering and technology enter industry or government service immediately after earning their baccalaureate degree. A few remain at the universities to pursue additional research-based graduate education as preparation for academic scientific research positions. Of those who enter industry or government service, most assume leadership roles in the practice of engineering for technology development within five years.

The opportunity for engineers and technologists to pursue further graduate study is limited across the nation, with notable exceptions, to either pursuing the M.S./PhD. route for scientific education for academic research or the MBA route for business education. Although each of these educational paths is excellent for their specific intent, neither of these routes is adequate, sufficient, nor specifically designed to meet the further professional development needs of engineers and technologists who are growing as technology leaders in industry. The engineering path of technology leadership for systematic needs-driven engineering innovation is a unique responsibility of the higher levels of systems-oriented “engineering practice” by which further technical, ethical, and professional competency is gained through actual progressive engineering experience and further graduate professional studies. Although this interdisciplinary type of professional-oriented graduate education for engineers must utilize educational resources from a university’s total educational and research system, it is more than simply combining business education with engineering education. The engineering leadership of systematic needs-driven creative technology development and innovation in industry is a unique professional practice of advanced engineering.
It is now understood that engineering and technology leadership is *neither* practiced solely *nor* was it ever practiced solely at the first undergraduate education level for entry in “engineering practice.” But pre-service undergraduate engineering education does serve as the preparation for entry into practice as well as the basic educational foundation on which the engineer and technologist can build his/her further growth and advanced professional studies in combination with progressive experience. There are nine progressive levels of leadership responsibilities and proficiencies that extend beyond entry level in engineering that are recognized by the National Society of Professional Engineers (NSPE) for the innovative practice and leadership of engineering in industry and government service. 46

Subsequently, the “gap” that exists in the U.S. Science and Engineering (S&E) infrastructure for professional education in engineering must be filled by a deliberate, systematically, planned and coordinated educational transformation, which reflects a new type model of in-service graduate professional education for engineers that is concurrent with full-time employment in industry and that supports further in-service professional growth throughout the engineer’s professional career in a new unique way. Today, graduate professional education can be specifically designed for engineers in industry as a coherent educational matrix of advance studies that matches and supports the nine stages of “growth” in engineering practice.

**CONTEXT 4:**

*Reshaping Graduate Professional Education for U.S. Engineers in the Context of Innovation-Based Learning for the Future that Transcends Educational Obsolescence*

The design of further graduate professional education for engineers, beyond entry, must be formulated in a manner that supports the systematic practice of engineering to sustain continuous world-class technology development and innovation in U.S. industry. Whereas the conventional model of engineering education is usually defined as preparation for entry into practice, it is limited in scope in today’s changing concept of professional engineering education for innovation because it terminates at entry level and is limited to content-base learning.

Conventional professional education, based solely on a technical content model of professional education (and on the common belief of learning existing knowledge and then application for later practice) gives little room to the occurrence that innovative engineers grow beyond their formal degree levels or to the development of intrinsic creative human potential and innovative capacity that is required to create new technology, which results in new technological knowledge. Because of the explosion of scientific knowledge, however, the conventional belief of education, which is based largely on the linear research model of scientific knowledge generation, teaching, learning, focuses primarily on the transmission and acquisition of knowledge with later application in industry and has given rise to the traditional myth of the “half-life” of engineering education and obsolescence.

We would not take the myth of the “half-life” of engineering education and obsolescence seriously were it not that so many others *do* take it seriously. The myth is a professional falsehood if we truly educate our emerging engineers *for the future* in the basic fundamentals of engineering, in learning how to learn as self-directed learners throughout their professional careers, and in the engineering method which is a mainstay of the systematic engineering
innovation process itself: wherein experienced engineers and technology leaders do not become obsolete but they purposefully bring about the obsolescence of existing technology through their creative problem solving capacity and innovative leadership skills.

Nevertheless, the false myth of engineering education obsolescence is too prevalent among academic research-based faculty and is driven home too often to young undergraduate engineering students. Wherein sooner or later, they actually believe the myth — perhaps unaware of the fact that the traditional method of engineering education, which is based on the linear research model of engineering innovation is itself obsolete because the linear model is erroneous. But the subtle myth lingers on; and it is frequently expressed in strategic plans for undergraduate engineering education, as the following:

A decade ago, the half-life of the Mechanical Engineer was estimated at 7.5 years. Presently, the half-life is 5 years. Over the next decade, it is expected to be less than three years, i.e. less than the time required obtaining a B.S. degree. The demands are expected to even increase. Technological changes are not only influencing the engineer, but they also impact business and society. These changing requirements demand the establishment of a new culture in education, a culture in which both students and educators recognize and emphasize the dynamic nature of their fields.

This underlying belief of undergraduate engineering education, which hopefully only a few hold, is absurd if we truly educate our emerging engineers for the future as we enter a new century of engineering and technological advance. Unfortunately, the belief exists at too many universities, with notable exception, which points to a decline in the quality of undergraduate engineering education during the 80’s and 90’s of which remnants exist today in 2001. There is no “half-life” to an engineer’s education as a profession if we truly “educate for the future,” by building undergraduate engineering education as a solid foundation which is based upon proven fundamentals, rudiments of design, basic sciences and humanities, and by teaching the undergraduate “to learn how to learn” through real-world project engineering work and self-directed learning.

This is not to say that new knowledge is not occurring. Of course it does. And it is occurring very quickly. The fields of Science and Engineering are dynamic and are ever changing. And they should be changing if research scientists at the universities and advanced engineers, technologists, and technology leaders in industry are doing their jobs. What else would we expect? But we must educate the nation’s creative engineers “to learn how to learn” and “to learn how to create new technology” through the use of the creative engineering method, wherein technology innovation becomes a continuous process and systematic practice of the engineer’s actual work in industry. The point to be made, as Isenson pointed out from the results of the Project Hindsight study, is that a modal point of seven and nine years of experience was often required for engineers to make meaningful contributions to the development of complex technological systems which exceeds the mythical notion of “half-life” of an engineer’s education. The lack of academic awareness within today’s universities of the modern requirements of real-world innovative “engineering practice” and what their engineering graduates do in industry and government service clearly points to the need for transformation in graduate professional education and to the great amount of work that needs to be done in re-
engineering higher education for responsive engineering and technology leadership for U.S. competitiveness (Dunlap, Aherne, Keating, Stanford, & Mendelson, 2001). 47

The change of culture that is needed in modern research oriented universities is one of building awareness that there is high-quality professional growth after the baccalaureate entry level which is not second rate but which is quite different from that which is given emphasis and current recognition by academic research faculty and administrators for the tenure and promotion of academic research faculty at today’s research universities. However, the underdevelopment of educating undergraduate engineering students for self-direct learning in professional life is quite serious. What Knowles pointed out in 1973 is evident today in 2001: 48

“For some time now I have been aware of the fact that the products of our educational system don’t know how to learn — they only know how to be taught … Recently, as I was reflecting on this sad state of affairs, it dawned on me that a more accurate way of conceptualizing this phenomenon was reactive versus proactive learning. For traditional pedagogy conditions the student to respond to the teacher’s stimuli; the initiative in the transaction is almost wholly in the teacher; the role of the student is to react … Previously, some learning results from being taught this way, but it keeps the learner in a dependent role and limits the learning to the boundaries set by the teacher. It is poor preparation for continuing to learn throughout a lifetime, which is what we are about in adult education.”

Today, high-quality graduate professional education must transcend the pervasive myth of the obsolescence of engineering education and “half-life” by providing a new educational approach for the further in-service graduate development of world-class engineers and technology leaders in industry which includes not only technical content but combines also the “critical skills” and “professional dimensions” of innovation-based learning needed for engineering creativity, invention, and innovative leadership in “engineering practice” for continuous creative technology development and innovation in the global economy. What Maslow pointed out years ago can now be implement today in the development of new teaching concepts that are required for further in-service graduate professional education for experienced working engineers and technology leaders in industry. As Maslow noted: 49

“What is then the correct way of teaching people to be, e.g., engineers? It is quite clear that we must teach them to be creative persons, at least in the sense of being able to confront novelty, to improvise. They must not be afraid of change but rather must be able to be comfortable with change and novelty, and if possible even be able to enjoy novelty and change. This means that we must teach and train engineers not in the old and standard sense, but in the new sense, i.e., “creative” engineers … This, in general, is also true of executives, leaders, and administrators in business and industry. They must be people who are capable of coping with the inevitably rapid obsolescence of any new product, or of any old way of doing things. They must be people who will not fight change but who will anticipate it, and who can be challenged enough by it to enjoy it. We must develop a race of improvisers, of “here-now” creators.

We must define the skillful person or the trained person, or the educated person in a very different, way that we used to (i.e. not as one who has a rich knowledge of the past so that he
can profit from past experiences in a future emergency). Much that we have called learning has become useless. Any kind of learning which is the simple application of the past to the present, or the use of past techniques in the present situation has become obsolete in many areas of life.”

**CONTEXT 5:**

Reshaping Graduate Professional Education for U.S. Engineers in the Context of The Critical Skills and Professional Dimensions Required in “Engineering Practice” for the Responsible Leadership of Systematic Technology Development and Innovation in Industry

Whereas undergraduate engineering education is primarily technical content-centered and focuses on sequential learning for postponed application, the new model for further in-service graduate professional education must be designed differently in the context of concurrent professional education that supports the engineer’s on-going creative “engineering practice” in industry and it must be developed as a “content-process” model of advanced professional education, which supports the further professional development of the graduate engineer’s technical competence as well as the “critical skills” and “professional dimensions” that are required for the progressive leadership responsibilities, roles, and mission that engineers assume in industry beyond entry level.

As Cranch, former president of ASEE, former president of Worchester Polytechnic Institute, and former Dean of Engineering at Cornell University, notes: There are several dimensions that form the professional imperative of an engineer’s education. As Cranch points out: Undergraduate engineering education is already too crammed to put much more into it at this level of growth and the undergraduate student neither has the professional maturity factor nor the actual experience factor to fully develop the professional dimensions and critical skills for leadership in engineering practice, although a beginning can be made. Because of the progressive leadership responsibilities and dimensions inherent to the nine stages of growth in the innovative practice of engineering for creative technology development in industry, beyond the baccalaureate, it is no longer sufficient to think of the education of the engineer as a professional as a one time-experience of consecutive undergraduate educational experience and then practice at the entry level.

Because the characteristics of excellence for academic scientific research and for the creative practice of engineering for innovation are profoundly different, the contexts of their respective types of further graduate education are quite different. Whereas curriculum development for pre-service entry level education for the professions is formulated upon several common elements, e.g. technical competence and ethical responsibility for practice, the formulation of the new type of model of further in-service graduate professional education that provides further opportunity to enable engineers and technologists to continuously grow beyond their entry level baccalaureate degree, as creative professionals in industry, must include not only the further development of technical and ethical dimensions but also the fuller development of mission, purpose, professional responsibility, and the development of other in-service professional dimensions, which are now unique to the modern practice of engineering and technology leadership in today’s engineering contexts.
The new model of further in-service graduate professional education can be specifically designed for the nation’s engineers that provides high-quality further graduate professional education concurrently in combination with on-going innovative practice for systematic technology development in industry, and which coherently matches and supports the progressive responsibilities and dimensions of “engineering practice” throughout the career-long growth of experienced engineers who are assuming increasingly responsible roles in technology leadership positions in industry. As Scheffler points out: Unless we arbitrarily restrict education to the sphere of knowledge, we must admit that the development of “critical skills,” “propensities,” and “character” falls within its scope. Thus, the education of the engineer as a growing professional must now include not only the transmission and acquisition of relevant scientific and technical knowledge but also the development of “critical skills” that are required for “actual creative practice and performance.” And these critical skills must correlate with creative “engineering practice” which reflects the new model of needs-driven engineering innovation for competitiveness.

For academic scientific researchers, the critical skills correlate with inquiry-based learning and the scientific method in the context of research investigations and the generation of new scientific knowledge. For engineers, however, the critical skills correlate in the context of “engineering practice” and the use of the engineering method for creative problem solving, needs-finding, technical program making, engineering judgment, ethics, decision-making, vision, and technology policy making for the creation of new technology and the creation of new engineering knowledge.

As Scheffler has pointed out: “The ambiguity of practice is thus of paramount importance in the education of skill.” Because of the ambiguity of new problems that arise in professional practice, as Scheffler notes, “these critical skills are not routinizable, but involving always an ineliminable engagement of judgment in the performance.” However, with the singular emphasis on academic scientific research and on research-based graduate education as the forerunner and pacesetter for engineering innovation during the 70’s, 80’s, and 90’s, the “critical skills” for creative “engineering practice” were not being developed to the same extent during this time period as those critical skills for scientific research. As Ferguson noted: “It would become painfully obvious (during the 70’s) that engineering faculties had become strong in “engineering practice.” Nor did the teachers have the necessary industrial experience to introduce students to the many subtle, unstructured problems of designing, building, operating, and maintaining structures and machines.”

CONTEXT 6:
Reshaping Graduate Professional Education for U.S. Engineers in the Context of Developing Engineers as Systems Integrators, Innovators, and Leaders of Technology

It is now recognized worldwide that in order to contribute most effectively to technology innovation and the creation of wealth, graduate engineers need to develop throughout their careers as innovators and leaders of technology (Keating, Stanford, Self, Monniot). Graduate professional education for engineers must be specifically designed as a new type of advanced graduate education that extends through the highest leadership levels of the practicing engineering profession in industry and government service.

Proceedings of the 2001 American Society for Engineering Education Annual Conference & Exposition
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As Gregory points out: 53

• “Engineers carry out a wide range of functions, central among which is some kind of design activity and some kind of executive activity.”

• “Engineers tend to see creative design performance and its enhancement as their special professional way of contributing to social advance. But new designs produce no effect until they are embodied in a suitable material form and then set into operation or put to use by the ultimate consumer. For the engineer, creativity is only meaningful within a completed innovation sequence of this kind.”

• “Engineers are now inevitably concerned with systems in one way or another. These are largely systems, which undergo life-cycle changes; growth and decay are characteristics of modern technology and society. The wide range of engineering functions take place within this complex of changes and are conditioned thereby. Engineers who are managers are system managers. They manage the systems which have been built or they manage the processes by which new systems are planned or brought into being.” 28

CONTEXT 7:
Reshaping Graduate Professional Education for U.S. Engineers in the Context of An Integrative Curriculum that Combines Progressive Experience, Advanced Studies, and Self-Directed Learning Concurrently with Actual Creative “Engineering Practice” in Industry

Although many of the nation’s universities are research-oriented, and focus on the creation of new scientific knowledge and the education of future academic researchers, they still can provide the niche and resources that are required for the new type of further graduate professional education specifically designed for the nation’s engineers in industry even though the curriculum and method of teaching is different. The curriculum that is needed for professional-oriented graduate education for engineering practice must be integrative in nature and must reflect the needs of the practicing profession in industry.

The curriculum for an engineering professional’s further graduate development is not based on scientific specialization but rather is based on the progressive growth of the professional competency of the engineer as a technology leaders, who is growing both in depth, breadth, and professional responsibility. Correspondingly, the professional oriented curriculum is not oriented toward the transmission and acquisition of technological knowledge but rather toward an integrative program of study, experience, and actual creative performance which further develops the engineer as a creator and leader of new technology, which also results in the creation of new engineering knowledge (technological knowledge). Such a curriculum is designed from a systems approach to develop the whole engineer and requires the integration of progressive experience, advanced studies, self-directed learning, and actual creative performance in innovative “engineering practice” itself in industry.

As creative knowledge professionals and change agents, innovative practicing engineers and technology leaders in industry not only learn the existing state-of-the-art of their field of technology through self-directed learning in industry, as well as learning relevant scientific
knowledge that is needed in the industrial development process, but they also create new
technological knowledge as a result of their deliberate creative contributions to technological
development through the conceptual engineering design process, and quite often direct the thrust
for needed strategic research through their leadership capacity.

Today, the innovative practice of engineering and its leadership for creative technological
innovation in industry is itself an innovative-learning experience, and the integrative professional
curriculum must reflect a new type of learning for creative technology development, which
requires the further development of the innovative capacity for self-directed learning, original
creativity, ingenuity, and innovative leadership skills to flourish. No longer can advanced
professional education be considered as a passive learning experience, separated from actual
practice, or as simply the result of traditional knowledge transfer and acquisition of knowledge
from faculty to students.

CONTEXT 8:
Reshaping Graduate Professional Education for U.S. Engineers in the Context of
Creative Problem Solving, Technical Program Making, Technology Policy Making, Ethics,
Judgment, and Transformative Leadership for Systematic Technological Innovation in U.S.
Industry

Whereas the broad aim of undergraduate engineering education is to prepare young men and
women for entrance into the practicing profession and to lay the basic foundation of engineering
fundamentals for further graduate study, the aim of graduate professional education must be to
foster the further growth of experienced graduate engineers and technologists, after entry into the
profession, toward the development of their fullest creative-leadership potentials for innovative
professional “engineering practice” in industry or government service.

As the National Research Council report, Engineering Education and Practice in the United
scientific discovery and technology development will give further impetus to a revolution in
engineering practice. With the use of new tools and methods the work of many engineers will
become increasingly abstract, involving formulation of ideas and choosing among
development options. Therefore engineers will need to be able to deal with problems in
unfamiliar contexts, they will need to be knowledgeable about scientific advances generally, and
they should understand the fundamentals of innovation.”

Toward this realization, the purposeful reshaping of graduate education for engineers in industry
must reflect this revolution in engineering practice for innovation by focusing on the
development of a coherent curriculum that address the main functions of what engineers do and
the progressive dimensions of engineering leadership. From this perspective, the curriculum
focuses on professional education as lifelong “growth” in the context of the various stages of
engineering responsibilities, which include the following areas: creative problem solving,
technical program making, technology policy making, ethics, judgment, and transformative
leadership for systematic technological innovation in industry. Innovative professional
engineering education at the advance level must include the further development of technical
competence, creative human potential, engineering leadership skills to lead collaborative
interdisciplinary groups and large scale technology development programs, professional
responsibility, creative flexibility and versatility to tackle new meaningful innovative engineering work, and develop creative wisdom gained through experience for needs-finding, program making, and technology policy making in socio-economic-technology issues in the global arena.

Whereas “the ability to design” lays the basic foundation and is the primary differentiating characteristic between an engineering education and a scientific education at the undergraduate level of an engineer’s career-long professional development, the further development of creative engineering problem solving, technical competence, professional responsibility, strategic technical program making, technology policy making, judgment, and change leadership for continuous systematic technological innovation are the progressively differentiating characteristics of an engineer’s further in-service advanced professional education versus a graduate scientific education for inquiry-based learning and discovery. As change agents and as creative knowledge professionals, innovative engineer-leaders in industry not only learn the existing state-of-the-art of their field of technology through self-directed learning in industry, as well as learning relevant scientific knowledge that is needed in the industrial development process, but they also create new technological knowledge as a result of their deliberate creative contributions to technological development through the conceptual engineering design process, and quite often direct the organization’s thrust for needed strategic research through their engineering leadership capacity.

**CONTEXT 9:**
Reshaping Graduate Professional Education for U.S. Engineers in the Context of The Known Attributes of Part-Time Graduate Professional Education for Working Professionals

At the advanced level of an engineer-leader’s professional growth, he or she is primarily learning on their own or in collaborative creative groups wherein the technology innovation process itself is a learning-developmental activity, which requires proactive involvement and engagement. This requires a paradigm shift in graduate professional education, which is quite different from undergraduate education, which primarily focuses on didactic instruction and knowledge acquisition.

At the advanced professional level, faculty and students engage in collaborative learning and collaborative creativity, wherein the terms “faculty” and “students” no seem longer applicable. Perhaps better terms would be “faculty/facilitators” and “participants” who are both full-fledged practicing professionals and who both are continuous learning professional in innovative practice. At this level, professional education takes on a whole new meaning and definition and is probably defined as a process of actualizing creative human potential in actual meaningful “engineering practice” through the unique combination of professional learning-by-doing, engineering experience, advanced studies, and meaningful creative professional work.

During the past three decades, the United States has undergone a major educational transformation across the nation in which part-time graduate programs have become a major part of the nation’s educational infrastructure for working professionals. These part-time graduate programs have been a “silent success” across the United States, as the National Study by the Council of Graduate Schools has determined. As Conrad and Haworth have pointed out:
The attributes of part-time graduate professional programs, which contribute to the quality of stakeholders’ educational experiences include: a) Diverse and Engaged Participants, b) Participatory Cultures, c) Interactive Teaching and Learning, d) Connected Program Requirements, e) Adequate Resources.

CONTEXT 10:
Reshaping Graduate Professional Education for U.S. Engineers in the Context of Further Professional Education Beyond the Baccalaureate Through M.Eng., D.Eng., and Fellow Levels for the Engineering Leadership of Systematic Technology Development and Innovation

Based on the long-term success of various part-time professional masters programs in operation across the country there is now both the experience factor and the educational foundation to extend first-rate graduate professional education beyond the baccalaureate and masters level to the doctoral level and Fellow levels of professional growth. What we are hearing across the nation, after working professionals complete their masters, is what’s next? As the 1995 NRC Reshaping Report reflected: 56 Most graduate engineers are pursuing professional careers that are not centered on research but are centered on the professional practice of engineering and the leadership technology development in industry which is quite different from scientific research and academic specialization. For them a new complementary type of graduate professional education is needed, not as a “stepping stone” through Ph.D. studies for academic scientific research, but one which serves as high-quality graduate professional education that extends through the professional master and doctoral levels of engineering, and through the Fellow level for creative leadership in innovative “engineering practice” in industry. Such a program correlates with the nine stages of growth in professional practice and is not limited to advanced studies for academic research specialization.

Although the primary aim of research-based graduate education for scientific research is to educate young graduate students as specialists in their fields in order to perform independent original scientific research and investigation, the primary aim of graduate professional education for engineering is to further educate experienced engineers as technology leaders in their field of technology in order to perform original needs-driven creative technology development and responsible leadership of collaborative original systems development/improvement which often involves the development/improvement of complex technological systems.

As Gardner, former Secretary of Education, and former president of the Carnegie Corporation and the Carnegie Foundation, points out: 57 “The colleges and universities, particularly the graduate and professional schools, drive students down the road to specialization. Leaders have always been generalists. Tomorrow’s leaders will, very likely, have begun life as trained specialists, but to mature as leaders they must sooner or later climb out of the trenches of specialization and rise above the boundaries that separate the various segments of society. Young potential leaders must be able to see how whole systems function, and how interactions with neighboring systems may be constructively managed.”

As Gardner notes, “leadership development is the product of a lifetime of study and action.” Today we must unlock the innovative potential of the nation’s engineers and technology leaders by providing a new approach for graduate professional engineering education that continues their
growth after entry into the practicing profession, and which fully develops the innovative capacity of our domestic engineers as technology leaders. Engineering education can no longer be construed as a four, five, or eight-year process which terminates. The education of the nation’s engineer-leaders as creative professionals is a lifelong growth process, which involves the further development of technical, creative, innovative, professional responsibility, and leadership potential. It is now evident that engineers progress through four broadly defined areas of progressive technology leadership responsibility, which correlate with the specific NSPE subset levels. They are:

a) Entry level engineer responsibility

b) Project engineer levels for technical project management responsibilities

c) Technical manager/engineer levels for systems engineering and technical program management responsibilities

d) Executive systems engineering levels for organizational engineering leadership and strategic technology development policy and value judgment making responsibilities

CONTEXT 11:
Reshaping Graduate Professional Education for U.S. Engineers in the Context of Globalization of Technology Development and Innovation in the New Economy

Global competitiveness is of paramount concern to the engineering community worldwide and has been for some time. Today, competition in the global arena is “head to head” as Thurow has pointed out. 58 America’s capability to compete in international engineering innovation is dependent upon two lessons learned. First, we must recognize that today’s model for the needs-driven, market-focused engineering innovation process is different from the sequential, linear research-driven model of engineering innovation. Second, we must strengthen the nation’s professional educational infrastructure for engineering leadership and we must harmonize the curriculum development of graduate professional education for engineering leaders in industry with the characteristics required for today’s innovative practice of engineering for sustained strategic advantage in the global economy.

As Fenster, points out: 59

“Increasingly, the engineer plays a key role in responding to the rising aspirations of people everywhere for a better life. This greatly enhances the professional components of the engineer’s role. … Engineering curricula are influencing both the more developed and less developed economies, as all are fueled by the dynamics of the marketplace and are making the transition from “imitators” to “initiators.” They needn’t go through every step from the industrial revolution to the present. They can learn from the mistakes and the accomplishments of the more developed economies and recognize that good economic policy and good social policy can go hand in hand. And they know that today’s innovation is tomorrow’s commodity, so that there is an ongoing need to innovate. The diffusion and the deployment of knowledge are so rapid that there is little time to sit back and admire our
successes. There is information exchange and joint research and development occurring across national boundaries everywhere. … We have learned that global economic movements do not need to be a zero sum game, so that we can be participants in an inspiring movement to raise the living standards and quality of life of all people. This fundamental view of the role of the engineer in economic and social changes that are evolving across the globe must be reflected in the manner in which we educate and prepare engineers of the future.”

CONTEXT 12:
Reshaping Graduate Professional Education for U.S. Engineers in the Context of Combining a Core University Faculty with Distinguished Practicing Professionals in Industry

Whereas traditional research-based graduate scientific education builds upon the conventional model of a strong resident faculty of academic researchers who are actively engaged in sponsored research and the education of future academic researchers, the new complementary model of advanced graduate professional education for “engineering practice” requires no less excellence. But it builds upon the integrative strengths of a professional-oriented university core faculty combined with the professional engineering strengths of an adjunct distinguished practicing professionals in competitive U.S. industry.

The combined faculty represent interdisciplinary strength and expertise of industry. It would also draw upon the distinguished faculty strengths that exist within other areas of the university itself. Such models have worked well in different regions of the nation and represent a very practical and a very effective way in which to build a formidable professional-oriented faculty of excellence, that is second to none, and who are at the cutting edge of technological innovation. Such a faculty does not represent the traditional “ivory tower” approach to teaching, but rather a tested professional-oriented group who have actual real-world experience in “engineering practice” for creative technological development and innovation in industry and who want to help others learn, grow, and develop to their fullest potential. Such a faculty does not compete with the traditional research faculty because both types of pursuits are needed equally well in the U.S. Science and Engineering (S&E) innovation system. What better way to learn scientific research than to learn with a senior faculty of researchers doing research: and what better way to learn engineering innovation than to learn with a senior faculty of experienced distinguished engineers doing engineering innovation within industry.

CONTEXT 13:
Reshaping Graduate Professional Education for U.S. Engineers in the Context of Building an Experienced Practicing Student Body of Emerging Technology Leaders in Industry

Whereas the student body that is pursuing traditional research-based graduate education is composed of young men and women who are seeking scientific research careers in academia, the student body that is pursuing further in-service professional-oriented graduate education is different in type, talents, purpose, and objectives. The participant-student body that is pursuing further in-service graduate professional education is composed of experienced of graduate engineers (minimum of 2 - 3 years experience) who are already full-fledged engineers employed in regional industry and who are pursuing professional careers not centered on research. Whereas the traditional graduate research student is a resident in the research university and is a full-time
student, the professional-oriented student is a continuous part-time student with residence in both industry and the university. As the National Study for the Council of Graduate Schools pointed out: 60 Most working professionals who pursue master’s degrees are seeking a kind of advanced education designed to expand their understanding and improve their skills so that they can be more effective in their careers.

 Whereas graduate enrollments are in decline across the nation, and many new Ph.D. can not find jobs in academia, graduate professional education does not replace research-based graduate education but provides a new balance in professional education where the participants are already employed and will continue to be participants in the university’s regional outreach for the long-term in their careers. Although traditional graduate research students represent an expense to the university, they do assist the academic graduate research in their further work and ability to receive federal research grants. Graduate professional students, however, represent added revenue to the university and provide a mechanism for better engagement with regional industry in the continuous advancement of needs-driven engineering innovation to enhance regional economic development and U.S. competitiveness.

 Whereas universities across the nation are in stiff competition with each other to attract top graduate students for academic research, the addition of graduate professional education provides a complementary balance where top professional-oriented students are already within the region, are fully employed, and are graduates from some of the best engineering schools in the nation and world. The practicing student body in graduate professional education are the cream of the crop in American industry and represent a formidable student body of world-class engineers for the regions economic development and growth. By providing opportunity for high-quality graduate professional education that further develops innovative engineers in U.S. industry for creative engineering innovation will provide the opportunity for the fuller growth of the university, industry, and the region together to enhance the nation’s competitiveness. As the National Study for the Council of Graduate Schools pointed out: This type of graduate education for working professionals — “is probably the most direct link between society and higher education.”

 CONTEXT 14:
 Reshaping Graduate Professional Education for U.S. Engineers in the Context of Developing Innovative Technology in Industry and Engineering Leaders Simultaneously to Enhance U.S. Technology Competitiveness

 The need for this complimentary type of further in-service graduate professional education, for working engineers and technologists in industry, grows in importance as the rate of technology competitiveness in the global economy by other nations increases. The need for this educational change is threefold. First, the new model of further in-service graduate professional education must support the new model of engineering innovation itself. Second, the model of further in-service graduate professional education must support the roles, the responsibilities, the professional dimensions, and the various stages of professional growth for engineering leadership that experienced engineers and technologists encounter in advanced practice. Third, the model of further in-service graduate professional education must support the integrative
learning processes by which working professionals learn, grow, and develop in creative professional practice.

Whereas traditional research-based graduate programs have rightfully become programs of integrative graduate education and scientific research for inquiry-based learning and “discovery,” it is equally obvious that professional-based graduate programs for engineering and technology leadership must become programs of integrative graduate education and engineering practice for innovation-based learning and “creativity” in the context of “engineering practice” in industry. As Scheffler notes, critical skills and competences are generally developed through actual practice. This is the epitome of the engineer-leader’s continuous learning and growth process, which is best developed in combination with actual practice in needs-driven creative technological development. Thus, it is now evident that the “critical skills” that are required for the “practice of engineering” for innovation in industry, which ultimately results in the creation and development of new techniques and the development of “new technological knowledge,” must be reflected by the development of a new innovation-based model of graduate education for “practicing engineers,” which is based on the engineering method for needs-driven systematic engineering innovation. Combining actual creative engineering practice and advanced graduate professional education simultaneously best develops these critical skills.

Therefore, recognizing that an engineer’s advanced education is predominantly a technological education for engineering innovation and creative problem solving rather than a scientific education for academic research and discovery, it is now evident that a mainstay of further graduate professional education for engineers must be to not only engage engineers in learning “procedural knowledge,” that is, in “knowing how to” conduct significant real-world engineering innovation responsive to unstructured needs but to actually do real-world needs-driven engineering innovation in industry. This recognition lays the foundational premise for developing a new type of in-service professional-oriented graduate education for engineers in industry that integrates the engineer’s advanced education simultaneously with on-going creative technology development in industry as a synergistic learning experience that further develops engineers as innovators and leaders in industry. Thus, the advanced education of engineers for “engineering practice” goes beyond the teaching of “knowing existing facts and propositional knowledge:” it includes also the teaching of “knowing how to” create “new techniques” and the teaching of “knowing how to” creatively solve new real-world problems and needs that have not been effectively met before through creative engineering.

Thus, a mainstay of graduate professional education for engineers and technologists is a substantive technology development project/thesis in industry, which adds value to the participant’s sponsoring industry and to the educational growth of the engineer-leader. Whereas the use of distance education is very important to this type of graduate study, it does not serve every purpose for the developmental growth of the participating engineer or the participating professional faculty for real-world, hands-on learning and collaborative creativity. Such a technology project/thesis serves to further the development of new/improved technology within regional industry as well as to serve as to promote the development of new collaborative creative groups within industry and the university, which will further reinforce enhanced innovative capacity for technology development within regional industry as a core competence.
What Vannevar Bush did for the advancement of U.S. scientific research and graduate education, by creating a compact between federal government and the nation’s research universities and a unique system of graduate education that promotes the advancement of scientific progress and the education of high-quality academic researchers simultaneously, can also be done in engineering. We now have the capability of developing a compact between U.S. industry and the nation’s universities to create a unique system of high-quality graduate professional education in the United States that can develop competitive technology in industry and high-quality engineers simultaneously throughout their careers, thereby increasing the innovative capacity of American industry multifold, stimulating continuous engineering innovation for technological progress, and enhancing the competitiveness of U.S. industry for sustained economic prosperity.

The potential impact of this approach to U.S. technological competitiveness is significant. If each university in the collaborative alliance for this transformation can continuously enroll 100 graduate engineers in their graduate professional education programs, then the collaborative alliance of 5 universities will stimulate 500 new technological improvement and innovations in products, processes, systems, and operations across the nation to enhance U.S. competitiveness. If 10 universities join the collaborative alliance, this means that 1000 new improvements and technological innovations can be brought to fruition in enhancing and sustaining America’s technology-based industry. This educational method provides the sustaining opportunity for the United States to be preeminent in both graduate education for scientific research and graduate professional education for engineering.

CONTEXT 15:

Today, America has the resources, which other nations do not have in total, to further strengthen its systemic Science and Engineering (S&E) infrastructure for economic competitiveness by building upon its combined strengths in scientific research at the universities and by providing a new type of university graduate professional education for engineering and technology leadership in industry. The key to this transformation is in building new engagement mechanisms between industry, university, and government to continuously stimulate new technological innovation in industry, and to allow this transformation to occur.

The United States can build upon its unique strengths for competitive advantage by using the American devised systems approach to needs-driven technological innovation and by building closer relationships with regional and national research universities that further strengthen the professional education function and the scientific research function in an integrative manner. This will require the cooperation of industry, universities, and state/federal government working together to stimulate U.S. innovation. This unique integrative approach will deliver a formidable strength unequaled in the world with significant returns. The time to implement this integrative educational and research improvement to better support the needs-driven “R&D” process in industry is upon us. But universities cannot provide this change by themselves, nor should they. The change requires a new type of collaborative partnership between universities, industry, and government to accelerate the path forward.
7. The Challenge of Transformation in Reshaping Graduate Professional Education for Engineers in Industry

7.1 The Stakes are High: It’s a Matter of Economics for U.S. Industrial Competitiveness

Because of global technological competitiveness, the stakes are too high for the United States not to transform graduate professional engineering education to further develop the innovative leadership capacity of engineers and technologists in industry as creators, developers, innovators, and leaders of technology to continuously enhance U.S. technology competitiveness. The “knowledge-based, innovation race is on” and nations worldwide are revisiting their policies to improve domestic innovation. Whereas other nations, such as the U.K. and France, are still primarily pursuing the linear research-driven model of innovation, the United States must recognize that the model of engineering innovation itself has changed substantially, adjust to this transformation for competitive advantage, and build upon its unique proven, integrative strengths in science and engineering (S&E) by using an integrative systems approach to technological innovation through needs-driven creative systems engineering and directed scientific research — but also nurturing curiosity-driven scientific research to thrive at the universities.

The biggest problem, however, in improving America’s graduate educational infrastructure for engineering innovation is to recognize the national significance why transformation needs to be made to improve U.S. competitiveness. As Lester Thurow, former dean of MIT’s Sloan School of Management, points out: 61

“The American problem does not lie in the severity of the necessary solutions. America’s tough problem is realizing that there are problems that must be solved. Without that realization, nothing can be done … In the past half century the world has shifted from being a single polar economic world revolving around the United States to a tripolar world built upon Japan, the European Community, and the United States … Sharp changes will be forced upon the United States as for the first time in a long time it confronts economic and technological equals.

In the next century the United States will be just one of a number of equal players playing a game where the rules increasingly will be written by others … Whatever Americans think, the wealthiest parts of the industrial world see themselves forging ahead of the United States. … No one can solve a problem they refuse to see … Americans are no longer in a position to force the rest of the world to play the economic game by its rules, but Americans can play the game by their rules … Systematic bench marking reveals that the United States does not have to undergo a period of blood, sweat, and tears to regain its productive edge … But America is going to have to find a uniquely American way to develop a game plan.”

7.2 Reinforcing America’s Competitive Edge through Graduate Professional Education to Enhance U.S. Ingenuity, Inventiveness, Technology Leadership and Creativity in Engineering

One promising strategy in building a formidable American game plan for innovation is to build upon an integrative plan that links university graduate professional education for engineers and
university directed research to industry’s on-going technology development projects to stimulate engineering innovation in U.S. industry across the nation. Today, as never before, it is imperative that the nation recognizes that its graduate engineering and technology leadership base in industry is one of the nation’s major strategic resources and innovative strengths for the conceptualization, invention, development, and leadership of continuous, purposeful systematic technological improvements and breakthrough innovations that sustain U.S. competitiveness and economic growth in the global economy. Thus one of the quickest ways for the United States to strengthen its innovative capacity and industrial productivity is through the fullest educational development and utilization of its creative engineers and technologists in industry. As Whitfield points out: “It is taken as self-evident that the creative output of engineering will be raised quickest and over the widest area by successful efforts to improve the creativity of the engineer already in industry, specifically the engineer who has added an adequacy of experience to his basic technical training.”

The facts are now clear. Continuous engineering innovation for product development, process development, and increased manufacturing productivity is the driving force for U.S. economic competitiveness in the new economy. The importance for the United States to reinforce its professional educational infrastructure and innovative capacity in science and engineering (S&E) using the correct integrative model for technological innovation becomes obvious and rises to a national priority of importance. Because of the transformation of the innovation process itself, and because of the rapidity of technological change, by international competitors, it is equally obvious, then, that America’s capacity in sustaining competitive engineering innovation is dependent upon the nation’s human resource development efforts to further develop the innovative capacity and of its domestic creative engineering and technological talent in industry to stay ahead of the competition.

Equally important, then, is the need for the nation’s infrastructure in graduate engineering professional education to be responsively relevant to the professional development needs of advanced engineers, technologists, and technology leaders in industry; and to make a corrective transformation in graduate education across the nation, which reflects the substantial changes in the innovation process itself in order to enhance U.S. technology competitiveness. In essence, whereas America’s preeminence in fundamental scientific research is dependent primarily upon research-based graduate education and the scientific research capacity of its academic researchers at the nation’s research universities, America’s innovative engineering capacity for technological competitiveness is dependent primarily upon the engineering inventiveness, innovativeness, ingenuity and technological leadership capacity of its domestic engineers, technologists, and technology leaders in U.S. industry.

The time to provide educational improvement is at hand. But the improvement must build upon America’s existing strengths in both university scientific research and in university professional education as an integrative venture rather than separately. As Charles Vest, president of MIT, pointed out in 1992 at the keynote address to the American Society for Engineering Education: “All of higher education, and especially engineering education, requires a growing diversity of programs and kinds of institutions. In spite of my concentration on the research university, I believe that for too long we have all been striving for a single model: the comprehensive, Ph.D.
granting research university. We need different styles of education to meet the needs of different students.”

7.3 Rebuilding America’s Infrastructure in Professional Engineering Education

As Vest points out, today’s universities serve different constituencies and they have multiple missions, one of which is professional education and outreach to the professional engineering and technology community in industry. Whereas in the past, American graduate engineering education placed primary emphasis on the academic scientific research career path and the research-based graduate education of future academic researchers, because it sincerely believed that technology primarily flows from this pursuit, the professional path of engineering for the responsible leadership of creative technology development and innovation in industry has been too long neglected. And as the 1995 NRC Report, Reshaping the Graduate Education of Scientists and Engineers reflected: “Graduate schools can make substantial changes … A broader concern is that we have not, as a nation, paid adequate attention to the function of the graduate schools in meeting the country’s varied needs for scientists and engineers … Graduate education must also serve better the needs of those whose careers will not center on research.”

More than ever before, America’s competitive edge for technological innovation is dependent upon the fullest human resource development of its domestic engineers and technologists in industry and its resourcefulness to more closely link the nation’s engineering capacity in industry with the nation’s university scientific research capacity to accelerate needs-driven systematized technological innovation for U.S. competitive advantage. This is especially important today, when it is now known worldwide that the model of the engineering innovation process itself has undergone substantial changes and that the singular research-driven model of engineering innovation has proven to be erroneous. Needs-driven technological innovation is an integrative systems-oriented process, which uses both the engineering method and the scientific method when required in the needs-driven systematic “R&D” process. Quite often “D” drives “R.”

7.4 An Integrative Approach in Rebuilding U.S. Innovative Competitiveness Upon University-Industry Engagement By Linking Further Graduate Professional Engineering Education and Directed Scientific Research to the Systematic Technological Innovation Process in Industry

The issues in rebuilding advanced graduate professional education for the engineering leadership of systematic needs-driven technological development and innovation in industry are now known. It is now apparent that America must build its game plan for U.S. competitiveness upon the fuller development of the unique creative and leadership potential of its engineers and technologists in industry in synergism with sustaining its preeminent scientific research capacity at the universities.

America has long recognized that continuous systematic technological development is not a one-way street from the nation’s research universities to industry, but that it involves industry and research universities working together as a total unique system for innovation. And for over thirty years, whereas other nations have not, American engineering education has recognized that the further post-baccalaureate education of the nation’s engineers and technologists, who are already employed full-time in industry, is vitally important for continuous and systematic U.S.
technological progress for both the nation’s security and economic prosperity. Whereas some nations are still pursuing the linear research model for competitiveness, the United States has the unique opportunity, the combined strengths, and the total resources to pursue a systems approach to technological innovation for competitive advantage over the long-term. And the resources are already in place.

7.5 What’s Already Being Done

Although several universities across the country are already providing innovative graduate programs for engineers and technologists in industry, this is being done in piecemeal fashion, at best. The transformation in professional-oriented graduate education for engineers and technologists in industry to improve U.S. innovative capacity must be done systemically across the nation, starting with a critical mass of innovative universities, but the transformation requires a new conceptual basis for its implementation based upon the substantial changes in the innovation process itself that have already occurred.

The role of higher education in promoting innovative engineering capacity in industry is now recognized nationally and internationally as a significant catalyst for growth in the knowledge-based, innovation-driven economy. The need today, however, is not to reform research-based graduate education but to reshape a new complementary type of innovation-based, in-service further graduate professional education to meet the professional-oriented growth needs of in-place experienced working engineers and technologists in industry who are growing as technological leaders. In essence, whereas the existing infrastructure for research-based graduate education for the nation’s researchers is already in place, all that is required is to reshape graduate professional education for the further development of the nation’s engineers and technologists in industry who will become the technology leaders for tomorrow. This requires, however, that a pilot transformation for innovation-based, professional-oriented, in-service graduate education be allowed to occur and flourish at a critical mass of universities across the nation in order to serve as a demonstration project to further develop the nation’s domestic engineers and technologists in industry. For them, a new type of innovation-based graduate education is required to further nurture and foster their innovative and engineering leadership capacities.

7.6 Setting a New Vision in Graduate Education for Working Professionals in Industry

Higher education roles in support of the U.S. Science and Engineering (S&E) innovation system can no longer be limited to or based on the one-way context of “technology transfer” or “knowledge transfer” from research universities to industry, as the linear research-driven model of engineering innovation and knowledge transfer portrays. Today, higher education’s roles must include also the development of the creative potential of engineers and technologists off the university campus who also generate new technological knowledge and new technology. In other words, because technology is primarily created in U.S. industry by industry’s engineers and technologists, modern universities must not only be transmitters of new scientific knowledge but they must also be human resource developers of America’s creative professionals in engineering and technology who also create new technological knowledge. At the graduate level,
professional education includes more than instruction from teacher to student, but also includes collaborative learning and intellectual creative development of the human intrinsic potential.

Consequently, in this context, higher education takes on a new dimension of integrating graduate professional education and directed university research efforts to meet both the human resource development needs of industry’s engineers and technologists but also the directed scientific research needs of systematized technology development in U.S. industry. In order to improve U.S. Productivity, America must strengthen its innovative engineering capacity for both excellence in product development and excellence in process development, which is the responsibility of engineering leadership in U.S. industry. In turn, the nation’s research universities and regional universities must accept their challenge for strengthened engagement through enhanced professional education and directed scientific research to meet the needs of the practicing engineering profession in industry. This is a unique formidable strength, which is America’s edge for competitive advantage.

7.7 Conceptual Basis in Reshaping the Further In-Service Graduate Professional Education of Engineers and Technologists in Industry to Enhance U.S. Innovative Competitiveness

Whereas traditional research-based graduate engineering education and teaching have resulted during the last three decades, as a byproduct of the linear research-driven model with primary emphasis on the transmission, acquisition, application, and obsolescence of new scientific knowledge in industry, a new model of graduate professional education must be developed which focuses on supporting lifelong professional education for emerging and experienced engineers, technologists, and engineering leaders in industry as creative engineering problem-solvers, technical program makers, technology policy makers, and systems engineering leaders in the modern context of systematic technology development and innovation for competitive advantage.

Although the traditional model of research-based graduate education is adequate for the education of future academic researchers, it is neither adequate nor sufficient for the further post-baccalaureate graduate professional education of engineers and technology leaders in industry. Nor does it adequately support or reflect the needs-driven creative technology development process in industry — as it leaves out the fullest development of the innovative capacity of our domestic engineers and technologists in U.S. industry who invent technology, develop technology, and who lead the systematic process of needs-driven technological innovation. The linear research-driven model of innovation is outmoded, and must be supplanted by our better understanding of the transformation of the integrative model of the technological innovation process itself, which has occurred. A new innovation-based model of graduate professional education for the practice of engineering and technology leadership in industry must be developed which complements the existing model for research-based graduate education.

7.8 Technology Development as an Innovative Professional Learning Experience

Today, professional learning and the generation of knowledge does not just occur at the nation’s research universities nor is the practice of innovative engineering the application of what scientists do. Industry also generates knowledge by fostering invention, creativity, development,
and innovation to flourish within its organizations. Consequently, our approach to graduate professional education must be revised accordingly.

America’s edge for competitive advantage in the global economy is multifaceted, is dependent upon the understanding of the mechanisms of engineering innovation, and the recognition of the importance of high-quality professional-oriented graduate education programs that continue the further professional development of U.S. domestic engineers and technologists after entry into full-time employment in industry. Because a paradigm shift has occurred in the generative process of engineering innovation, a rethinking of the process of graduate professional education for engineering and technology leadership in industry must also occur.

The need to rethink the process of professional-oriented graduate education for the nation’s emerging and experienced engineers and technologists in industry is explicitly tied to improvement in the U.S. “R&D” system to sustain technological competitiveness for economic prosperity and to ensure national security. The transformation involves three strategic issues. First, a paradigm shift from a sequential, linear academic research-driven model of technology innovation to a new interdependent (S&E) model of systematized needs-driven technological innovation has evolved which integrates needs-driven creative engineering innovation in industry and directed scientific research. Second, the full strengths of the nation’s R&D and graduate education enterprise must be incorporated as a total integral system to support U.S. competitiveness. Third, new technology development and research partnerships must be built between industry, universities, and government that provide new engagement mechanisms, which continuously engages creative systematic engineering innovation in industry, university directed scientific research, and graduate professional education as key interdependent and interactive players to stimulate technological innovation and to enhance U.S. competitiveness.

There is now both the conceptual basis and the demand to reshape further in-service graduate professional education to meet the needs of working engineers and technologists in industry who are pursuing professional-oriented careers that are not centered on research but are centered on the responsible professional leadership of systematic technological innovation in industry.

Because innovation-based graduate professional education for the practice of engineering and technology management and leadership in industry is profoundly different from that of research-based graduate scientific education, the new educational model must reflect the intent of the practicing profession, which is creative professional service and the continuous advancement of innovative professional practice to meet real-world human needs. Thus, one of the primary aims of further in-service graduate professional education is to develop experienced responsible leaders within the profession who can bring about effective needed change. The need to educationally strengthen U.S. innovative engineering capacity and to further develop engineering leaders for technological change, within regional industry across the United States, is of national importance in developing America’s strategic advantage for competitiveness and sustainable economic growth.

It is now recognized worldwide that in order to contribute most effectively to technology innovation and the creation of wealth, graduate engineers and technologists need to develop throughout their careers as innovators and leaders of technology. Consequently, further in-
service graduate professional education must be formulated to support the innovative practice and advance professional work of engineering and technology management and leadership, beyond entry level, that is required to sustain world-class technology development and innovation in U.S. industry.

Because of the increasing dimensions and professional leadership responsibilities inherent to the innovative practice of engineering for the responsible leadership of technology development beyond the baccalaureate, it is no longer wise to think of professional education for engineering as a one-time-experience of consecutive undergraduate educational experience and then practice. A new model of specifically designed progressively advanced professional education can be designed which concurrently provides high-quality graduate professional education in combination with on-going innovative practice of systematic innovation and technology development and which coherently matches and supports the progressive responsibilities and dimensions throughout the career-long growth of the emerging and experienced engineer and technologist for technology management and leadership positions.

An extensive literature review by Aherne suggests that there is increasing awareness at a policy level that professional engineers must make conscientious and consistent efforts at lifelong learning which is performance-oriented and role-related. As Aherne has pointed out, the U.S. National Academy of Engineering (1998) identified career-long learning as an urgent issue for continued economic development and national competitiveness. The Academy notes that career-long education for engineers must address both the specialized needs for the practice of engineering and the knowledge needed for more interdisciplinary activities (e.g., leadership) that are required throughout the full duration of an engineering career. Moreover, as the Academy suggests:

“For today’s engineering profession, completion of the baccalaureate degree is insufficient to ensure career-long productivity or competence. Changes are needed, both to enhance further the predisposition of young engineers toward continuous professional development and to create stronger and more explicit systems for career-long education to which engineers can readily connect after completing their formal university-based training, regardless of geographical location, organizational affiliation, or degree-level attained…”

8. Conclusions

While substantial investment is being made in systemic reform at the K-12 level to improve the nation’s S&E enterprise, specific investment and reform needs to be made within higher engineering education itself to improve the graduate professional education of the nation’s engineers within industry who are the leaders of the systematic practice of technological innovation itself in U.S. industry.

The evidence for action is clear and the future looks bright. We are now at the end of the long time lag for resistance to educational change when America must reinforce its graduate professional education system to better support the innovative capacity of engineers and technologists in industry for creative engineering practice and technology leadership. There is growing awareness worldwide that the model for engineering innovation has changed.
substantially. The rebuilding of U.S. engineering practice for needs-driven, customer-focused systematic engineering innovation in industry is more crucial than ever in stimulating continuous technological innovation for U.S. competitive advantage.

8.1 The New Realities for Successful Systematic Engineering Innovation

The conditions for success in technological innovation clearly point to the vitally important roles that the nation’s engineers and technologists have as technology leaders in U.S. industry. The conditions for success also give evidence to the importance of how we define engineering innovation, how we professionally educate the nation’s engineers and technologists for engineering innovation, and how we organize and nurture the process of systematized engineering innovation in industry itself. Whereas conventional wisdom continues to define curiosity-driven basic scientific research as the forerunner of engineering, wherein innovation is popularly defined as the “exploitation, adoption and deployment” of new science-driven knowledge or the “ability to manage new knowledge”, these definitions are limiting at best and narrow in scope.

The model for successful engineering innovation has undergone transformation and the major source for the generation of new technology has changed. Although relevant scientific knowledge and relevant state-of-the-art technological knowledge are employed in systematized engineering innovation, the innovative mechanisms for creative engineering problem solving involve much more than just the application of existing/new knowledge to problems, as the erroneous linear research-driven model of engineering innovation implies. Today, both Science and Engineering (S&E) are central actors in the “R&D” process for technological innovation but they play different roles than the 1945 linear research model of innovation previously allowed. Industry is the major source for technological innovation, today, as the OECD findings and the Council on Competitiveness findings point out, and the nation’s engineers and technologists within industry are the primary creators, developers, change agents, and leaders for U.S. competitive technological innovation.

8.2 The Challenge of Transformation

The recognition that creative engineering in industry is a primary player in the technology innovation process, rather than a secondary/follow-on player to academic scientific research, as the linear research model previously defined, now places the engineering leadership of engineering practice for creative technology development in industry in a new light. And it also gives new meaning to the Vannevar Bush compact with the federal government to support the nation’s curiosity-driven research efforts at the universities. The proposed integrative model of combining needs-driven engineering innovation in industry, with directed scientific research, and with in-service graduate professional education for engineers-leaders in industry knows no national boundaries nor is engineering creativity and ingenuity limited to the United States.

What is required is to integrate the nation’s great creative strengths, innovative capacity, and higher educational capacity together through new collaborative partnerships between industry, government, and academia in order to refurbish the professional educational strengths and overall mission of the nations research universities/regional universities to integrate the research
strengths, the graduate professional education strengths, and the outreach-service strengths through new forms of engagement with the nation’s technology-based industry.

The challenge for America is to make this needed educational transformation through new partnerships, which will result in long-term benefits to industry, academia, and the nation for long-term economic prosperity. The task is underway. It is evident that the U.S. is picking up the pace for technology competitiveness and is recognizing the importance that graduate professional-oriented education and directed “R&D” play in promoting the advancement of both scientific progress and engineering progress for technological competitiveness of U.S. industry and our nation’s security. Academia, however, has long resisted this change and has been slow to adapt to the new model of needs-driven systematic engineering innovation—perhaps because of unawareness, vested interests or an unfounded fear of losing federal research funding and prestige. Whatever the reasons, the model for engineering innovation has changed.

In reality, if the nation’s research universities and regional universities meet the existing educational challenge across the country, the transformation to the new integrative model of engineering innovation in industry will provide the nation’s engineering and technology schools more funding, more prestige, and greater interaction with industry and government, through the integrative combination of providing enhanced university graduate professional engineering education and university directed scientific research to sustain meaningful technological innovation in U.S. industry for competitiveness in the global economy. America can meet this challenge through the collaborative creativity of its industry and universities working together.

8.3 Significance and Impact of Findings

What is the significance of our findings? First, there is growing awareness across the country that an integrative transformation in the U.S. Science and Engineering (S&E) innovation system and graduate education system is underway and that a paradigm shift has occurred. The combined OECD findings and the Council on Competitiveness findings reflect that technological innovation is dependent upon: certain conditions for success, “innovation best practice”, reshaping graduate education for engineers and technologists in industry, and providing effective engineering leadership and innovative organizational learning cultures for continuous systematic engineering innovation in industry. Nevertheless, substantial changes need to be accelerated in higher education for the United States to regain its technological leadership.

Second, although the federal government has had a science policy of supporting fundamental scientific research and research-based graduate education in both science and engineering for scientific progress, it has primarily placed singular emphasis for the development of technology for the civilian economy largely on a linear research-driven model for new technology, wherein the creation of new scientific knowledge would be generated at the nation’s research universities through basic scientific research as the “intellectual capital” and driving force for technology innovation. Although this model has been successful in providing superior U.S. graduate education for academic scientific research and discovery, the linear research model is neither sufficient to sustain U.S. engineering competitiveness in the global economy nor is it sufficient to serve any longer as the foundation basis for the advanced graduate professional education of...
U.S. innovative engineers and technologists for the practice of engineering and technology leadership in industry.

Third, numerous calls for needed transformation in professional education to strengthen the nation’s innovative capacity through enhanced engineering innovation in industry, technology leadership, and specifically designed professional-oriented graduate education for engineers in industry have been made by voices in the wilderness but academia has been slow to answer the calls. It is now time, however, that we do so. The task at hand is overcoming the resistance. There is growing national awareness that the graduate professional education of the nation’s engineers and technologists must undergo broad sweeping revision, which reflects harmonizing professional curricula with the transformation of the engineering innovation process itself.

Fourth, although there has been singular emphasis with federal funding to support the nation’s research universities by the linear research model of innovation for civilian economic growth, the contributions of the nation’s research universities can be greatly enhanced, rather than diminished, by the needed transformation to better integrate directed university scientific research and professional-oriented graduate engineering education to meet the needs of engineering innovation in U.S. industry. In the past, arguments have been made to singularly justify the importance of undirected basic research as the forerunner of engineering, which it is not. Undirected basic research is vitally important but so is engineering. Too often the innovative practice of engineering has been cast in the realm as the application of the results of what research scientists do, which it is not. They are both needed. Research & Development, however, are not one word or a sequential activity. The pervasiveness of the linear research-driven model, however, has been enormous at the expense of innovative engineering in industry and at the expense of providing further professional-oriented graduate education for innovative engineering practice to meet real-world needs of people.

Fifth, the reengineering of graduate professional education that is specifically designed to support educational transformation for career-long learning, growth, professional development, and leadership for creative engineering practice in industry can now be made. The resources are at hand and this is an idea whose time has come. The transformation neither threatens the research mission nor detracts from the research efforts of research faculty or their institutions, rather it serves to strengthen the professional education mission of universities. It provides closer interaction and engagement with industry through the integrative combination of needs-driven directed research and graduate professional education to better meet the needs of engineers and the systematic engineering development of technology in industry; and it provides increased revenue, increased prestige, and increased graduate enrollments, which are in decline across the nation. This integrative transformation can occur through the development and implementation of unique university-industry-government collaborative partnerships by working together in new engagement mechanisms to strengthen real-world engineering innovation in U.S. industry. This requires that U.S. industry take a more prominent leadership role in rebuilding U.S. innovative engineering capacity by forming long-term working partnerships with regional universities in order to promote local economic development in the global economy. The United States can no longer afford to do otherwise when other nations are investing heavily in the education of their engineers and technology leaders.
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DONALD A. KEATING
Donald A. Keating is an Associate Professor of Mechanical Engineering at the University of South Carolina teaching in the areas of mechanical engineering and the engineering leadership of technology. He received his M.Sc. in Mechanical Engineering from the University of Dayton and the M.Eng. in Mechanical Engineering from Cornell University. He has extensive experience in managing complex systems engineering development.

THOMAS G. STANFORD
Thomas G. Stanford is an Assistant Professor of Chemical Engineering at the University of South Carolina teaching in the areas of thermodynamics and chemical process design. He received his Ph.D. in Chemical Engineering from the University of Michigan.

DUANE D. DUNLAP
Duane D. Dunlap is an Associate Professor of Industrial Technology and the Founding Director of the Weekend Master’s Degree Program of the School of Technology at Purdue University. He holds degrees in technology and education and received his Doctor of Education from Virginia Tech.

MICHAEL AHERNE
Michael Aherne is an Associate at the Institute for Professional Development at the University of Alberta. He holds degrees in business and education (adult, career and technology education) from the University of Alberta. He has a broad range of consulting, management and operations experience in Canada’s education, international energy, health and transportation industries.

MEL I. MENDELSON
Mel I. Mendelson is an associate professor of mechanical engineering and director of the engineering and production management graduate program at LMU (Los Angeles, CA). His interests include failure analysis, integrated product development and creative problem solving. He received his B.S. from UC Berkeley, his M.S. and Ph.D Northwestern University all in materials science. He has 20 years of industrial experience.